Quantifying the Addition of Nitrogen to Agricultural Land by Groundwater via Irrigation

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Abstract

The concentration of nitrate in groundwater in Canterbury has significantly increased primarily due to land use intensification, resulting in reduced water quality. The region therefore is faced with the need to effectively manage land use to improve nutrient management. As the land is primarily used for agriculture, nutrient management is fairly complex. An increase in the use of fertiliser 20 to 30 years ago still affects water quality on the Canterbury Plains, due to the long lag times in the groundwater. Monitoring by Canterbury's regional council has shown that these effects are now being detected in many groundwater aquifers.

With new nutrient load limits currently being enforced across the Canterbury region, farmers are faced with a challenge to reduce nutrient losses from their land. However, this can be difficult to do while still maintaining economic productivity and therefore finding suitable management techniques is an urgent requirement for farmers. This research investigates whether nitrogen in irrigation groundwater can be used to partially replace nitrogen fertilisers, in the Selwyn and Ashburton Districts in Canterbury. Using the nitrogen in the groundwater, as an alternative to fertiliser, could also reduce the amount of nitrogen in groundwater, by recycling nitrate back onto agricultural land and turning an issue into a solution.

Sixteen farms were selected to participate in this study and data was primarily collected through informal surveys with farmers. Monthly groundwater samples were collected from each farm's groundwater well and analysed for nitrate-nitrogen concentrations. The nutrient modelling programme OVERSEER® was used to determine how nitrogen losses vary based on three different nitrogen application scenarios for selected farms.

The contribution of groundwater nitrogen to agricultural land is heavily dependent on the nitrate-nitrogen concentration in groundwater, the amount of irrigation water applied and the size of irrigated land. These scenarios modelled through OVERSEER® showed that nitrogen loss estimates can be improved using the actual measured nitrate-nitrogen concentrations in groundwater rather than using OVERSEER® default values. Fertiliser application also adjusted nitrogen losses based on the contribution of nitrogen from irrigation water.

By reusing the actual nitrogen data measured on farms in OVERSEER®, more accurate nitrogen losses can be calculated. This will become important when farmers need to comply with nutrient limits set as part of Environment Canterbury's Land and Water Regional Plan. The amount of solid nitrogen fertiliser used on farm can also be decreased in some cases without compromising pasture growth and allowing for a reduction in fertiliser costs. Results showed that some farmers could reduce nitrogen fertiliser by 21 percent, depending on their nitrogen contribution.

Farm Environmental Plans are now a requirement for farmers in the Canterbury region and they outline how environmental issues will be managed on the farm. Nitrogen contributions from groundwater may also be incorporated into the Farm Environmental Plan as a form of Good Management Practice, as nitrogen will be recycled through the farm system by irrigating the nitrogen lost back onto the land.

Table of Contents

List of Figures

List of Tables

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1. Introduction

1.1. Nitrate in Groundwater

Nitrogen is the most commonly recognised contaminant that is present in groundwater both worldwide and in New Zealand (Canter, 1997). Common sources include natural causes (i.e. geological nitrogen that is mobilised in groundwater) and anthropogenic causes including waste materials (i.e. septic tanks) and agricultural run-off (Canter, 1997). Nitrogen contamination in groundwater systems occurs naturally due to the interaction of the hydrological and nitrogen cycles but intensive land use alters either one or both of these cycles, which causes elevated groundwater contamination (Canter, 1997).

Agricultural land is a major source of nitrate contamination, particularly in New Zealand as 43 percent of the total land is used for agricultural purposes (The World Bank, 2015). Therefore, it is likely that groundwater resources will be vulnerable to contamination due to the interaction with agricultural practices on the land's surface (Foster, Cripps, & Smith-Carington, 1982).

1.2. Nitrate Groundwater Contamination from Agricultural Land

Agricultural contamination not only occurs in New Zealand, but is a common source of pollution around the world (Di & Cameron, 2002). Nitrate leaching is particularly prevalent in the Mississippi Basin in the United States, due to the use of fertilisers and pesticides on cropping farms (Goolsby, Battaglin, Aulenbacj, & Hooper, 2001). Furthermore, in Europe the nitrate groundwater concentrations situated beneath 22 percent of cultivated land exceed the World Health Organisations recommendations for drinking water (Laegried, Bockman, & Kaarstad, 1999). Australia has also experienced high nitrate concentrations in their groundwater throughout all states due to varying agricultural land uses (Thourburn, Biggs, Weier & Keating, 2003).

There is no denying that as land use changes and intensifies there is going to be impacts on the receiving groundwater environments. Contamination from agricultural land is caused by nitrogen sources including stock urine patches, septic tank effluent, animal feed pads and fertilisers (Enwright & Hudak, 2009). Vulnerability to leaching can also be increased depending on soil types, water recharge rates, irrigation rate and depth to groundwater

(Enwright & Hudak, 2009). This type of contamination is often referred to as a "diffuse source", which can be challenging to manage, due to the difficulty to implement, enforce and monitor practices used to reduce adverse effects (Trevis, 2012). This is because the source is often harder to identify compared to sources that have a direct discharge (e.g. treated wastewater discharged from a pipe) and there is no clear ownership of the issue (Trevis, 2012).

Nitrogen is essential for plant growth and when applied in excessive amounts (i.e. through fertiliser application and/or stock waste), plants are unable to consume the nitrogen and is leached into the groundwater or transferred through different pathways as shown in Figure 1 (Di & Cameron, 2002). Nitrogen-fixing bacteria in the soil are able to convert the nitrogen gas into readily available forms for plants to use (Canter, 1997). Through the process of nitrification, ammonium-nitrogen (NH_3-N) is converted to nitrate-nitrogen (NO_3-N) in the soil (Canter, 1997; Di & Cameron, 2002). When the nitrogen becomes nitrate it is leached into the groundwater system as soils cannot retain nitrate (Di & Cameron, 2002). The leaching process is driven by rainfall, irrigation, soil type and management practices (Pearson & Reynolds, 2007).

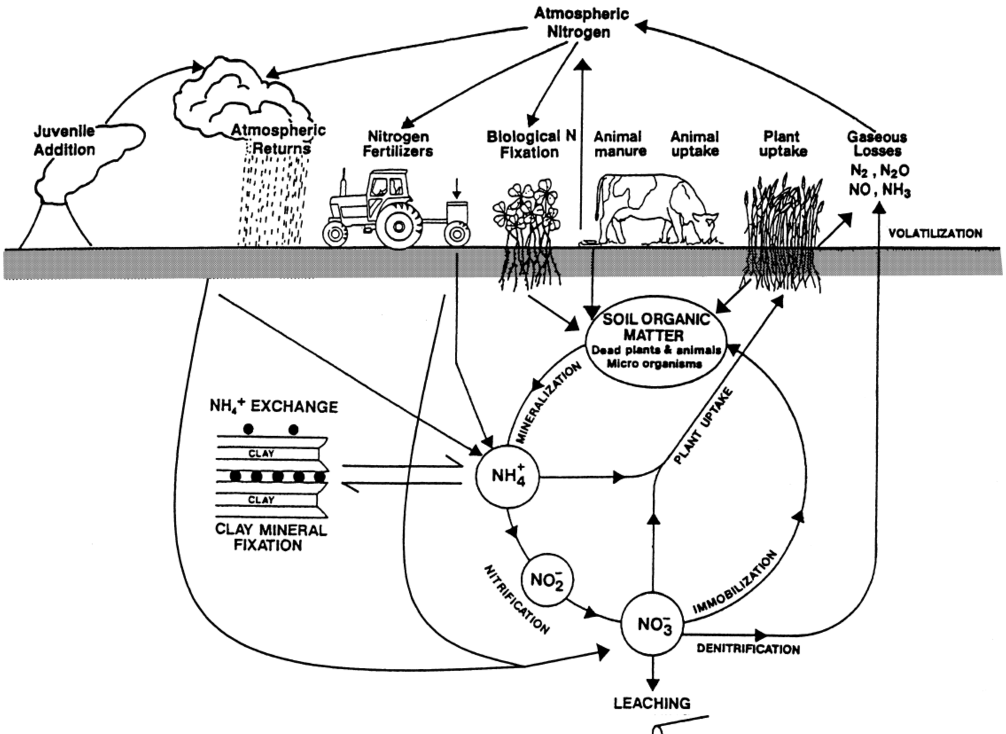


Figure 1: Transfer of nitrogen in a soil-plant system (Source: Di & Cameron, 2002).

1.3. New Zealand Agricultural Nitrate Issues

Agriculture is an extremely important industry in New Zealand as it produces 70 percent of New Zealand's export earnings with primary exports being dairy products and sheep meat (Ministry of Primary Industries, 2013). The agriculture industry has also employed 82,440 people which is over 2 percent of New Zealand's total population (Statistics New Zealand, 2006). Therefore, to maintain the country's economic production, New Zealand cannot afford to reduce or limit its agriculture production to improve the environment as it is simply not viable.

1.3.1. Fertiliser Use in New Zealand

In the last 20 to 30 years, New Zealand's agricultural industry has observed a dramatic change in land use, resulting in increased fertiliser use (Statistics New Zealand, 2006; PCE, 2013). The total amount of fertiliser used in the country has increased by 113 percent in the period from 1986 to 2002 (Statistics New Zealand, 2006). More specifically, the use of urea fertilisers has increased by 27 percent since 2002 (Statistics New Zealand, 2006; Ministry for the Environment, 2006). Urea is a common granular fertiliser that is used on dairy farms and is rich in nitrogen (Quin, Gillingham, Spilsbury, Baird & Gray, 2015). In 2014, an estimated 750,000 tonnes of urea was applied throughout New Zealand (Quin et al., 2015). Farmers typically spread their own urea fertiliser, not just to reduce costs, but to ensure that the urea is being applied at the most efficient time to enhance plant growth just after pastures have been grazed by stock (Quin et al., 2015).

It is important to acknowledge that fertiliser contribution to agricultural land is much less compared to other sources including stock urine due to the expansion of dairy farming in New Zealand (Scholefield, Tyson, Garwood, Armstrong, Hawkins, & Stone, 1993; Ledgard, Penno, & Sprosen, 1999; Di & Cameron, 2002). There is a direct relationship between fertiliser use and stocking rates as when more fertiliser is used to stimulate grass growth, the stocking rate increases, resulting in more stock urine.

1.3.2. Variability in Nitrate Concentrations

There are many factors that can cause nitrate leaching rates to vary including: the type of soil, the amount of rainfall or irrigation water applied and the plant's ability to uptake nitrogen (Canter, 1997). These factors also determine the nitrogen concentrations that are measured in groundwater (Canter, 1997). Throughout New Zealand, nitrate leaching mostly occurs during the winter when rainfall is higher (Di & Cameron, 2007; Statistics New Zealand, 2006). During winter, plant growth has slowed down and plants are consequently not utilising as much nutrients. This results in an increase in leaching into the groundwater system. Nitrogen concentrations are also influenced by groundwater origin, aquifer hydrology and geochemical processes that occur within the aquifer (Lincoln Environmental, 1997).

1.3.3. Effects of High Nitrate Concentrations

Effects on Drinking Water

Increases in nitrate concentrations creates issues for domestic, industrial and agricultural water uses as a particular minimum level of water quality is required. However, human consumption has the most strict water quality guidelines and these were developed by the New Zealand Ministry of Health. Currently the Drinking-Water Standards for New Zealand (DWSNZ) have a minimum acceptable value of 11.3 mg/L of NO_3-N (Ministry of Health, 2000).

These DWSNZ allow for protection against methaemoglobinaemia in infants that are bottle fed (Ministry of Health, 2008). This is also known as blue baby syndrome which is caused when there is an oxygen deficiency due to a reduction in the blood ability to carry oxygen to different parts of the body (Canter, 1997; Majumdar, 2003). Nitrate in water only become harmful to human health if they are converted to nitrite in the human body, resulting in methaemoglobinaemia (Canter, 1997; Majumdar, 2003).

Approximately 39 percent of New Zealand's monitored groundwater has increased above natural levels and exceed the DWSNZ of 11.3 mg/L of NO_3-N (Ministry for the Environment, 2007). Therefore, people are advised to source their drinking water from deeper groundwater wells, typically depths greater than 50 metres, as the nitrate concentrations are lower due to dilution (Chater et al., 2002).

Effects on Surface Waterway Ecosystems

High nitrate concentrations in groundwater can also threaten the health of surface waters due to the connectivity between these two water bodies. All groundwater eventually discharges into surface water including streams, rivers, lakes and coastal waters (Bidwell, Lilburne, Scott, & Thorley, 2009).

Nutrient enrichment in a water body is also known as eutrophication which reduces water quality (Smith, Tilman, & Nekola 1999; Paerl, 2009). Eutrophication can cause excess growth of unwanted species including algae and aquatic plants (Smith et al., 1999). The excessive growth of these can degrade ecosystem services provided by the water system as aquatic habitats become less desirable for fish species, due to fluctuations in oxygen levels and sedimentation (Smith et al., 1999; Davies-Colley & Wilcock, 2004). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality report outline how to control excessive algal growth and protect aquatic species (ANZECC, 2000).

Te Waihora/Lake Ellesmere in the Canterbury region is one particular water body where eutrophication has reduced water quality. The surface streams that flow into the lake are spring fed by groundwater. The nitrate in the groundwater are relatively high and this has contributed to excessive nutrients in Te Waihora/Lake Ellesmere. The lake has been rated as having the poorest nutrient status in New Zealand according to the National Institute of Water and Atmosphere's 2010 Lake Water Quality Report (Verburg, Hamill, Unwin, & Abell, 2010).

1.4. The Role of Groundwater Nitrogen in Pasture Fertilisation

There has been no specific research undertaken on quantifying the amount of nitrogen in groundwater that is applied to agricultural land. Lincoln University and the fertiliser company, Ravensdown, have however researched the response of grass growth to the application of nitrogen fertiliser in water applied through irrigation infrastructure, which is called 'fertigation' (Cameron, Di, Moir, Christie, & Pellow, 2005). Although this method is yet to be applied for dairy and cropping farms, it has successfully been used in horticulture (Cameron et al., 2005). The benefits of fertigation include more accurate nitrogen fertiliser application as well as reduced transport costs (Cameron et al., 2005). However, further research is needed to quantify these benefits for the dairy industry (Cameron et al., 2005).

1.5. Nitrate in Canterbury Groundwater

Canterbury's nitrate levels in groundwater have increased during the last 20 to 30 years due to land use changes (Burden, 1984; Trevis, 2012). The Canterbury Plains cover an area of 202,200 hectares and are used for various agricultural practices including dairy, sheep, beef and arable farming (Burden, 1984). These agricultural land uses have been operating for generations but it is due to the long lag time in groundwater that the high nitrate concentrations are being observed at present (Trevis, 2012). Increases in dryland sheep and beef farming 20 to 30 years ago caused an increase in fertiliser use and contributes to high nitrate in the groundwater measured today (Burden, 1984; Hanson, 2002).

NO_3-N concentrations can vary depending on the depth the water is being sourced from. Canterbury's regional council, Environment Canterbury (ECan), annually monitors groundwater NO_3-N concentrations at various depths in 10 zones located throughout Canterbury (see Figure 2). Majority of wells sampled are at depths of 20 metres or less and the remainder are between 20 and 100 metres. It is likely that higher NO_3-N concentrations are measured in shallower wells (20 metres or less) as any leaching from the surface will flow into these wells first (Trevis, 2012). Whereas in the deeper aquifers, NO_3-N concentrations are usually lower as dilution occurs (Trevis, 2012).

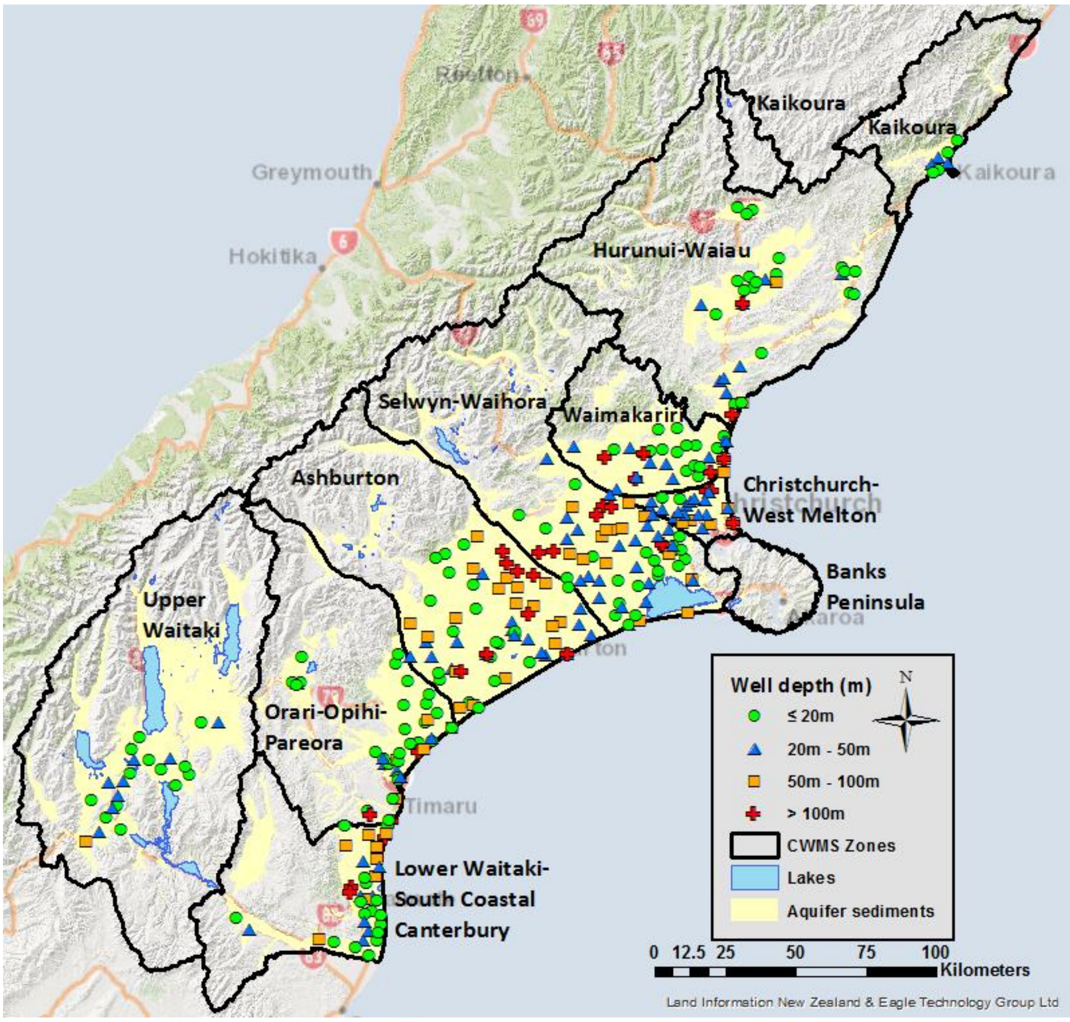


Figure 2: Various well depths in the Canterbury region (Source: Environment Canterbury, 2014).

1.5.1. Fertiliser Use in Canterbury

Canterbury has become the heaviest user in New Zealand of urea (nitrogen fertiliser), Di-Ammonium Phosphate (DAP) (nitrogen and phosphate fertiliser) and lime as shown in Figure 3. Urea use has also increased by 40 percent within the last 10 years in Canterbury (Statistics New Zealand, 2006), which is foreseeable as the region contains 70 percent of New Zealand's irrigated land (Saunders & Saunders, 2012).

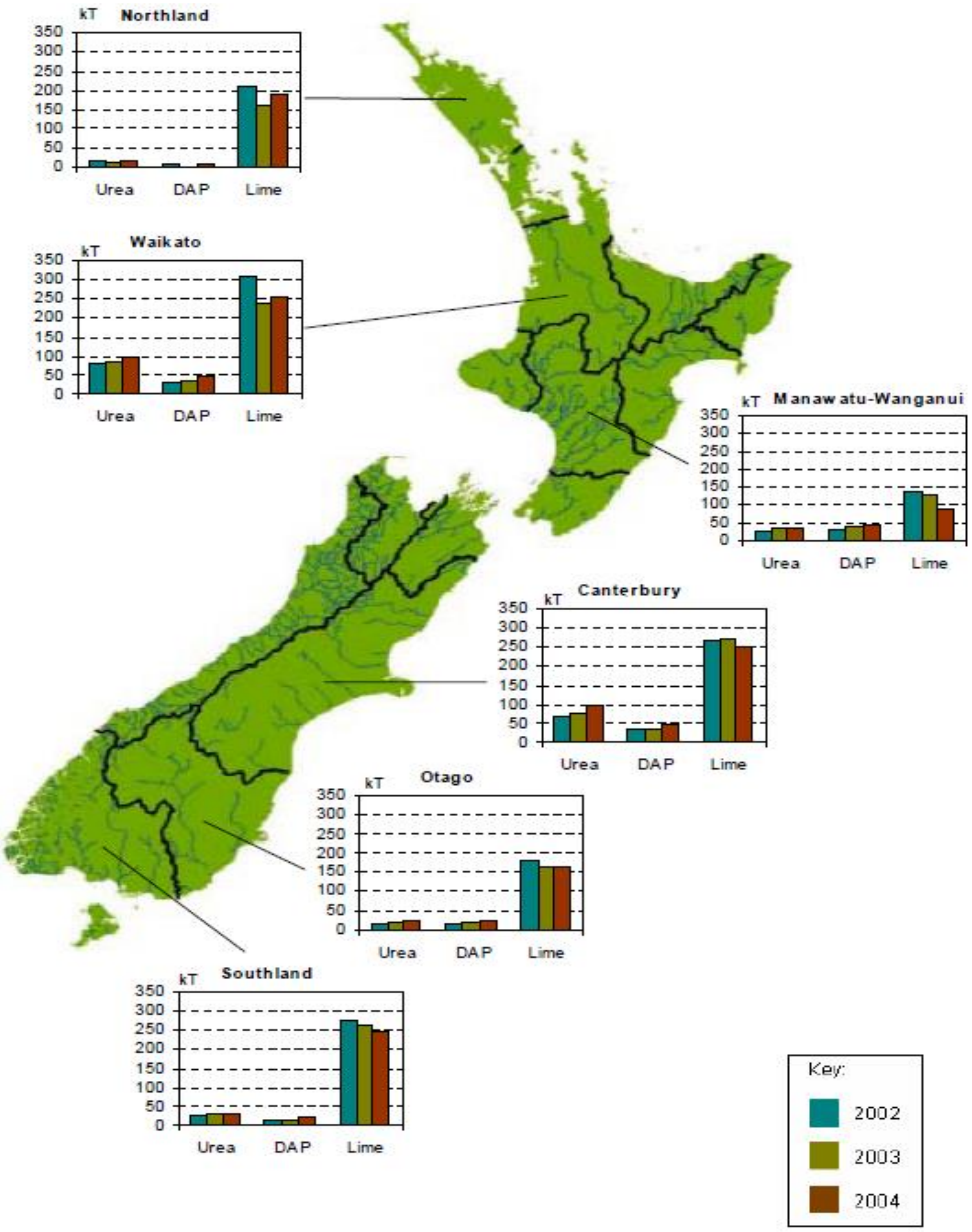


Figure 3: Regional use of fertiliser in New Zealand (Source: Statistics New Zealand, 2006).

1.5.2. History of Nitrate in Canterbury Groundwater

Nitrate that occur in the groundwater naturally usually have a concentration less than 3.5 mg/L as found in undeveloped areas in the United States (Nolan & Hitt, 2003). Concentrations higher than this suggest that there could be other sources of contamination. In 2013, ECan measured 205 wells in the region to determine trends and detect changes in concentrations over the last ten years. Annual monitoring found that 69 wells were increasing in NO_3-N concentrations (Environment Canterbury, 2014). These increasing trends were found in the Ashburton and Selwyn-Waihora Zones (Environment Canterbury, 2014).

Canterbury's groundwater is an important source for domestic, industrial and agricultural uses. Therefore, it is extremely important that water quality remains high to meet relevant standards. However, this is not apparent in some monitored wells in the region. As shown in Figure 4, approximately 8 percent of the wells in Canterbury exceed the DWSNZ (Environment Canterbury, 2014). Again, the majority of these are located in the Ashburton and Selwyn-Waihora Zones which reflects the ongoing agricultural development in these areas (Environment Canterbury, 2014).

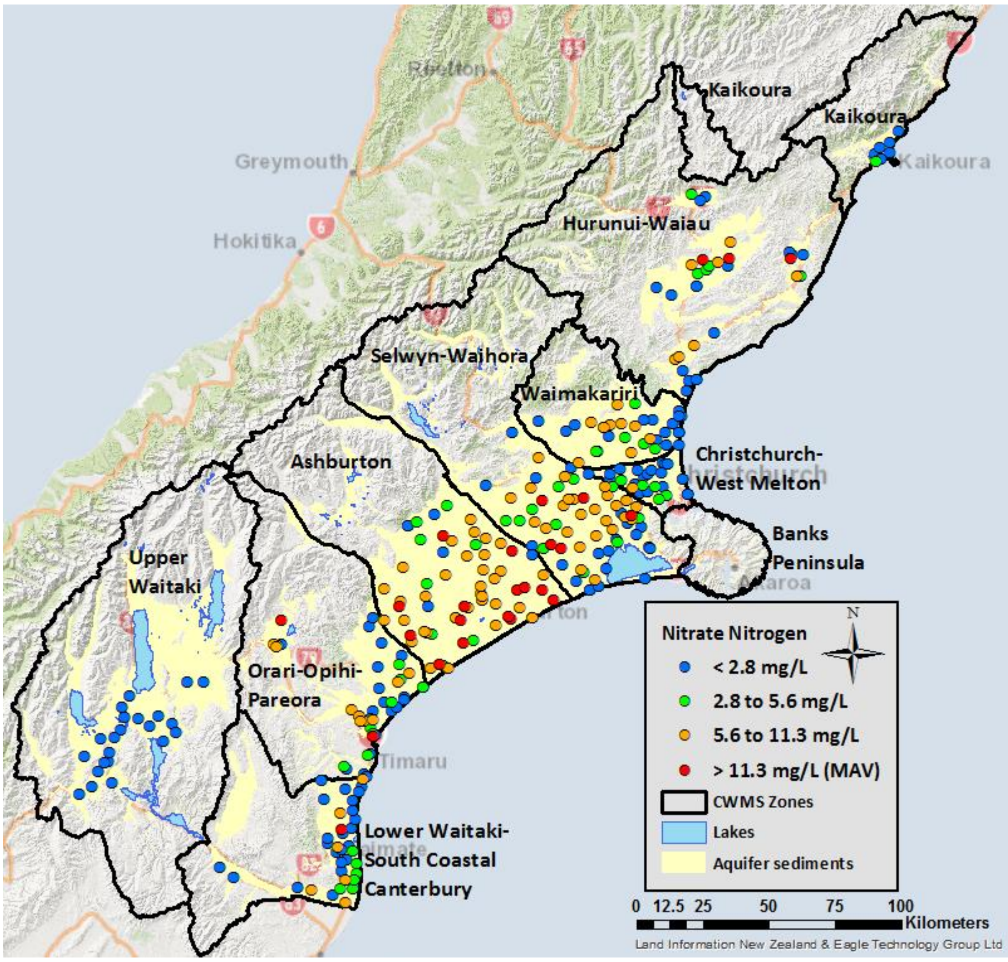


Figure 4: Surveyed wells in Canterbury that exceed DWSNZ of 11.3mg/L (shown in red) (Source: Environment Canterbury, 2014).

Prior to 2004, NO_3-N concentrations measured by ECan in groundwater wells ranged from 0.6 mg/L to 13 mg/L (Hanson & Abraham, 2010). However, more recent groundwater samples have shown that these concentrations have increased to 22.4 mg/L (Hanson &

Abraham, 2010). Therefore, some wells sampled exceed the DWSNZ and pose a potential risk to human health (Abraham & Hanson, 2010). These higher concentrations are associated with shallower groundwater wells on the lower parts of the Canterbury Plains (see Figure 5). Shallower groundwaters are more susceptible to leaching from the surface (Trevis, 2012). This is why groundwater used for human consumption should be sourced from deeper wells as nitrate concentrations are generally lower (Environment Canterbury, 2014).

Nitrate concentrations can vary depending on a number of different variables and this is apparent in Canterbury. In the central part of the Canterbury Plains, the soils are lighter, the sediment is highly permeable and the groundwater is well oxygenated (Hanson & Abraham, 2010). Therefore, nitrate concentrations are higher compared to other areas. Where soils are heavier and less permeable, leaching is less common and nitrate concentrations are lower (Hanson & Abraham, 2010). Figure 5 shows an increase in nitrate leaching in Canterbury between 1990 and 2011 and the leaching rates are significantly higher compared to other New Zealand regions. Nitrate leaching through soil in Canterbury is considered to occur in the winter through to early spring as denitrification rates are high in plant roots (Webb, Hewitt, Liburne, McLeod, & Close, 2010; Hanson, 2002; Hayward & Hanson, 2004).

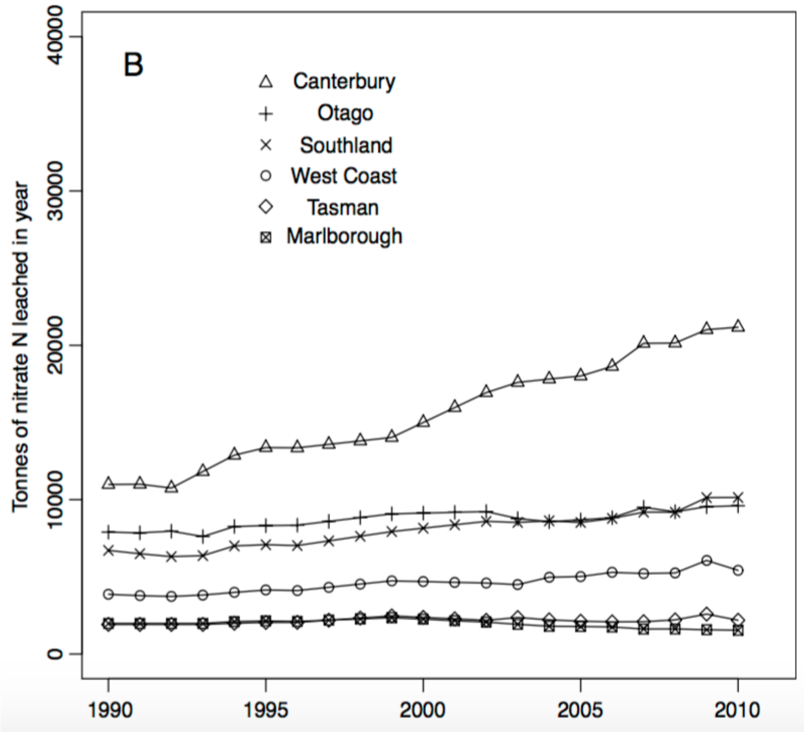


Figure 5: Variations in nitrate leaching rates in South Island, New Zealand regions (Source: Dymond, Ausseil, Parfitt, Herzig, & McDowell, 2012).

Forage crops (see Figure 6) that are used for feeding stock in the winter (e.g. kale, swedes, turnips, fodder beet) are also not as efficient at taking up nitrate, resulting in higher leaching rates (PCE, 2013). Therefore, areas where cows are wintered become hot spots for nitrate leaching and require effective management, which regional councils have recently begun to realise.

Figure 6: Dairy cows feeding on a winter forage crop (Source: PCE, 2013).

1.6. Management of Canterbury's Groundwater System

Both the New Zealand central government and regional councils have responded to declining water quality by implementing management strategies and regulatory guidelines (PCE, 2013). This includes the National Policy Statement (NPS) for Freshwater Management (developed by the Ministry for the Environment) which provides the overarching framework for freshwater management in New Zealand. Regional councils are responsible for developing regulations to meet requirements of the NPS. For example, ECan has developed the Canterbury Water Management Strategy (CWMS) which outlines regional freshwater management targets to be met. The CWMS was used throughout this research to help interpret the nutrient management strategies farmers should implement on their farm.

1.6.1. Canterbury Water Management Strategy (CWMS)

The CWMS was developed to improve freshwater management as the resource has become under tremendous pressure due to recent land use intensification (Canterbury Water, 2010). The CWMS focuses on managing different aspects of water including quality and quantity. Water quality and quantity are significant issues in Canterbury and the CWMS provide multiple management techniques that can be implemented. For water quantity this includes storing water either on farms or within an irrigation scheme. The CWMS is also used to produce nutrient limits to improve water quality, which is a main aspect of this research (Canterbury Water, 2010).

The Canterbury region has been split into ten different CWMS zones that are governed by their own committee (Canterbury Water, 2010). Each zone committee consists of representatives from ECan, the local government, Ngai Tahu, industry groups (e.g. DairyNZ) and community members that work collaboratively together to develop water management strategies for that particular zone (Canterbury Water, 2010). Each zone committee is responsible for producing a Zone Implementation Programme (ZIP) which outlines goals and pathways to meet water management goals.

1.6.2. Environment Canterbury's Land and Water Regional Plan

Zone committees are responsible for developing nutrient load limits for the catchment, and these have recently become rules in sub-regional chapters of ECan's Land and Water Regional Plan (LWRP). Within the LWRP, Section 4 and 5 as well as Schedule 8 outlines the overall regional rules for nutrient management. However, more specific rules for each zone are included within their own sub-regional chapter of the LWRP. The Selwyn-Waihora and Ashburton Zones will be used predominantly throughout this research and due to the poorer water quality and intense agricultural activity occurring in these zones, their rules and policies differentiate from the overall regional nutrient limits.

1.6.3. Selwyn-Waihora Zone Nutrient Management

Figure 7 shows the Selwyn-Waihora Zone boundary and within this area is Te Waihora/Lake Ellesmere. The lake has a large significance within the region as it is used for recreational activities and as a food source for local Maori. However, as explained previously the water quality has declined and become extremely eutrophic due to an influx of nutrients from surrounding water bodies. Therefore, the vision for the Selwyn-Waihora Zone is essentially to improve the state of the lake by implementing nutrient limits (Selwyn-Waihora Zone, 2011). Approximately 90 percent of the zone is used for agricultural purposes so most of the regulations are focused on reducing losses from this land (Snuckell, 2014).

Farmers in the Selwyn-Waihora must firstly establish a nitrogen baseline which is a five year average of nitrogen losses. These nitrogen losses are calculated using the nutrient budget modelling programme OVERSEER®. To determine the nitrogen losses, various data needs to be put into the model including the monthly amount of fertiliser applied, type of soil, effluent blocks, supplementary feeds, crop history, stock numbers, irrigation application method and climate data.

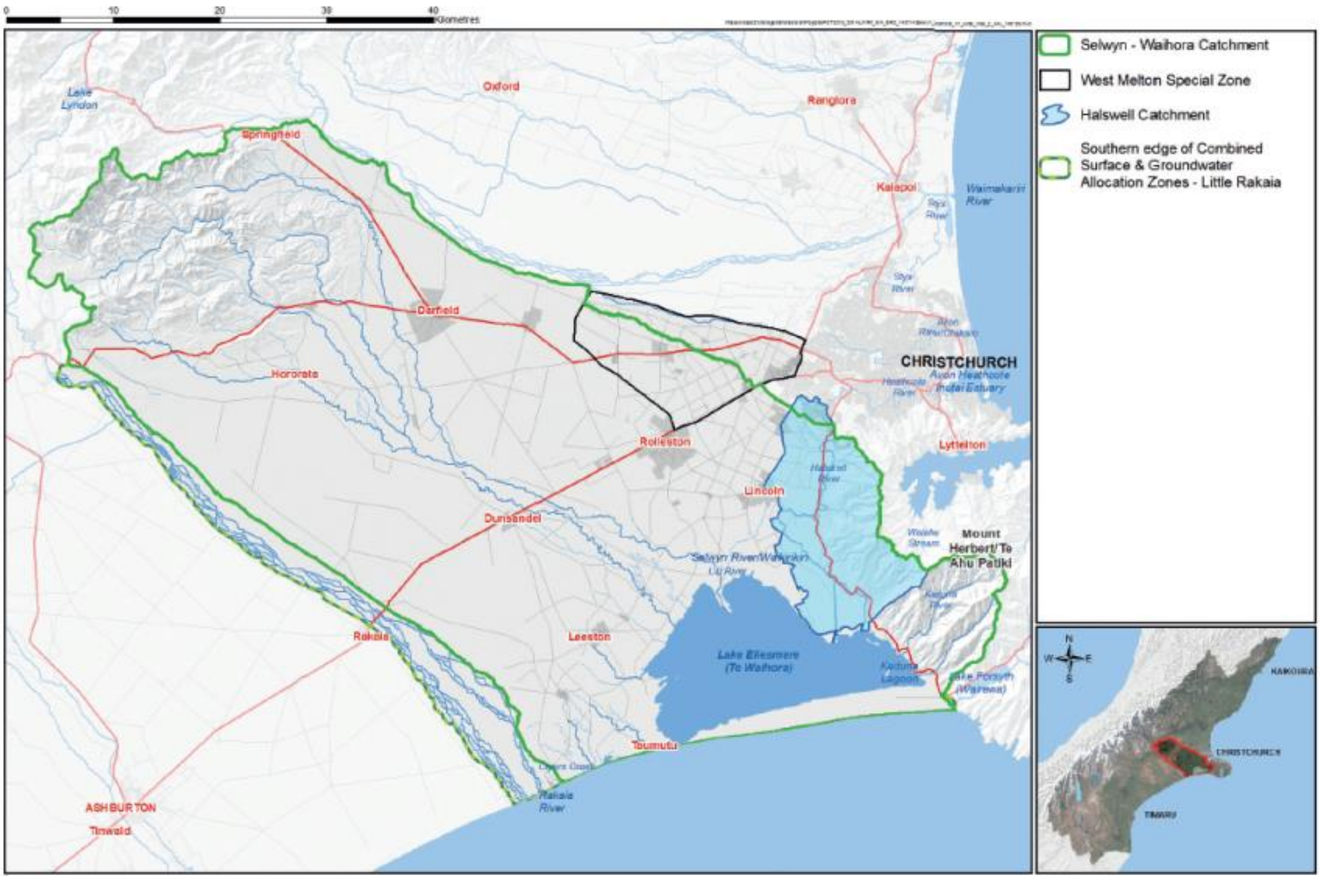


Figure 7: Boundary of the Selwyn-Waihora Zone situated in the Canterbury region (Source: Environment Canterbury, 2015).

The regulations in the LWRP state that up until 2017 farmers must not exceed their nitrogen baseline (Environment Canterbury, 2015). Good Management Practices (GMP) must also be implemented to reduce nitrogen losses on farms. Schedule 24 of the LWRP provides examples of GMP and ways in which nitrogen losses can be reduced. For example, this can include monitoring soil moisture to determine when and how much to irrigate as over irrigating can increase nitrogen losses (Environment Canterbury, 2015).

From the 1st of January 2017 onwards resource consent will be required if farm size is greater than 10 hectares and if the nitrogen loss rate is greater than 15 kg per hectare per year (Environment Canterbury, 2015). Resource consent will also be needed if the entire farm is or part of it is located within a Cultural Landscape Values Management Area or within a Phosphorous Sediment Risk Area (Environment Canterbury, 2015). Farmers must also be implementing GMPs according to Schedule 24 (Environment Canterbury, 2015).

For all properties that are greater than 50 hectares or have a nitrogen loss greater than 15 kg per hectare per year, a Farm Environmental Plan (FEP) is also required (Environment Canterbury, 2015). A FEP outlines how farmers are going to reduce and manage risks to the environment (i.e. nitrogen losses from land). These FEP's include irrigation efficiency, nutrient use, soil management, collected animal effluent, stock exclusion from waterways and cultural management (Environment Canterbury, 2014*a*).

From 2022 onwards, further reduction in nitrogen losses are required by farmers in the Selwyn-Waihora Zone. This again applies to all farms with nitrogen losses that are more than 15 kg per hectare per year, where an average reduction of 14 percent in nitrogen losses must be made (Environment Canterbury, 2015). This means that farming types including dairy farms will have to reduce their losses by 30 percent, while arable (cropping) farms will be required to have reductions of 7 percent (Environment Canterbury 2015). Farms that are greater than 20 hectares will also need a FEP from 2022 (Environment Canterbury, 2015).

1.6.4. Ashburton Zone Nutrient Management

Figure 8 shows the Ashburton Zone boundary which borders the Selwyn-Waihora Zone. The Ashburton Zone Committee's vision is relatively similar to the Selwyn-Waihora's Zone as it is desired that the water bodies quality in the catchment is improved (Ashburton Zone, 2011). This includes protecting ecosystem health and biodiversity where water quality has declined. Therefore, the zone committee has indicated that they are working towards implementing programmes that will effectively manage land use including nutrient limit developments (Ashburton Zone, 2011).

The Ashburton Zone has developed sub-regional rules which are included in Variation 2 of the LWRP. However, these sub-regional rules only apply to the Hinds/Hekeao Plains which is a sub-area of the Ashburton Zone (see Figure 9). These nutrient limits are similar to the Selwyn-Waihora’s in which they prevail over the region-wide rules. Areas not included in the Hinds/Hekeao Plains must however comply with the region-wide rules in Section 5 of the LWRP until specific rules are developed.

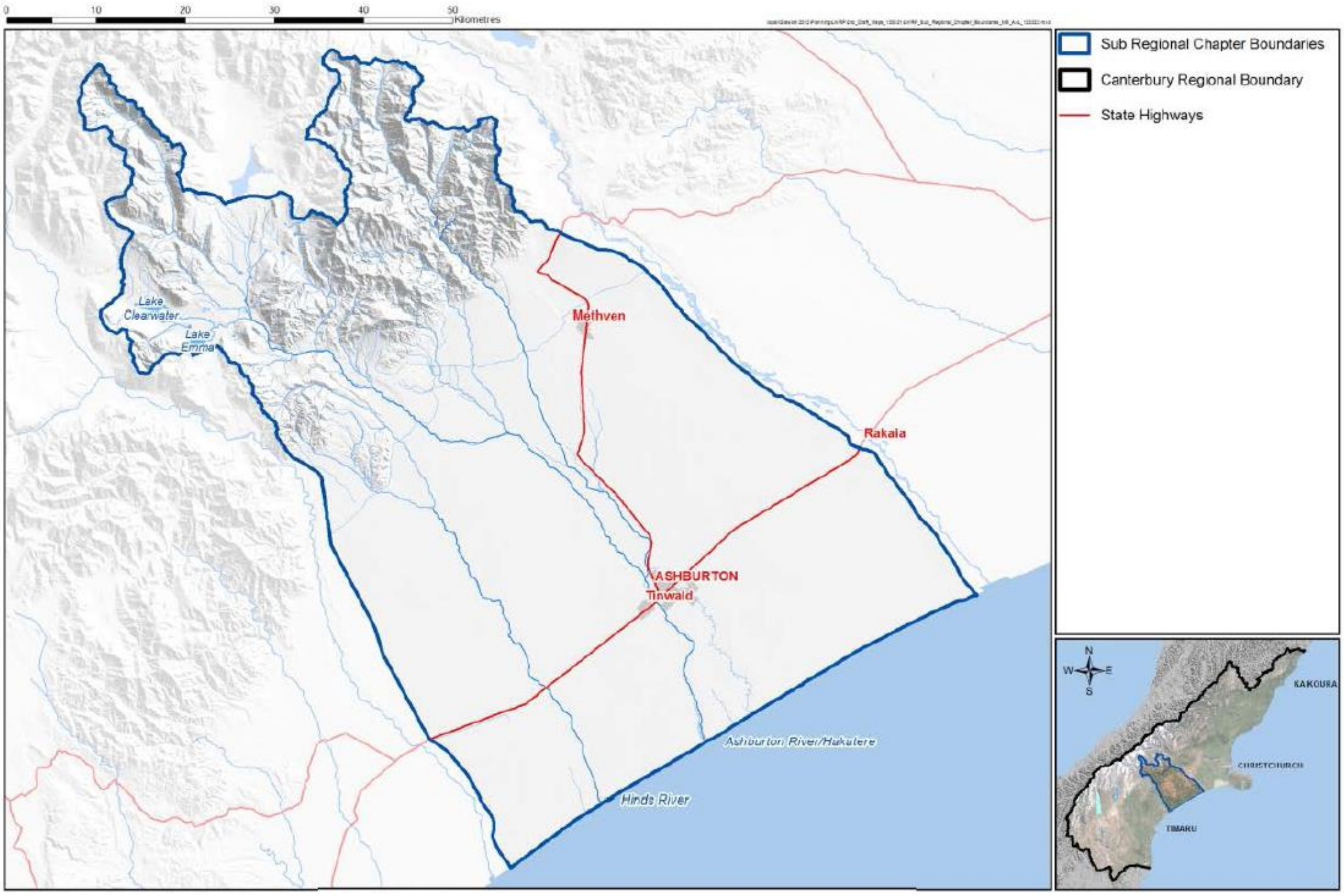


Figure 8: Boundary of the Ashburton Zone situated in the Canterbury region (Source: Environment Canterbury, 2013).

As shown on Figure 10, the Hinds/Hekeao Plains Area is split into upper and lower catchments and there are separate rules for each of these areas. However, for the purpose of this research the Lower Hinds/Hekeao Plains area will be the main focus. The regulations in Variation 2 of the LWRP state that until the 1st of January 2017, farms must not exceed their nitrogen baseline and must either implement GMPs or a FEP must be prepared (Environment Canterbury, 2014*b*).

However, from the 1st of January 2017 onwards, farms whose nitrogen losses exceed 20 kg per hectare per year must not exceed above their nitrogen baseline (Environment Canterbury, 2014*b*). Either GMPs must be implemented or a FEP prepared in accordance with the LWRP requirements (Environment Canterbury, 2014*b*). These farms will also require a resource consent if their nitrogen losses exceed 20 kg per hectare per year (Environment Canterbury, 2014*b*).

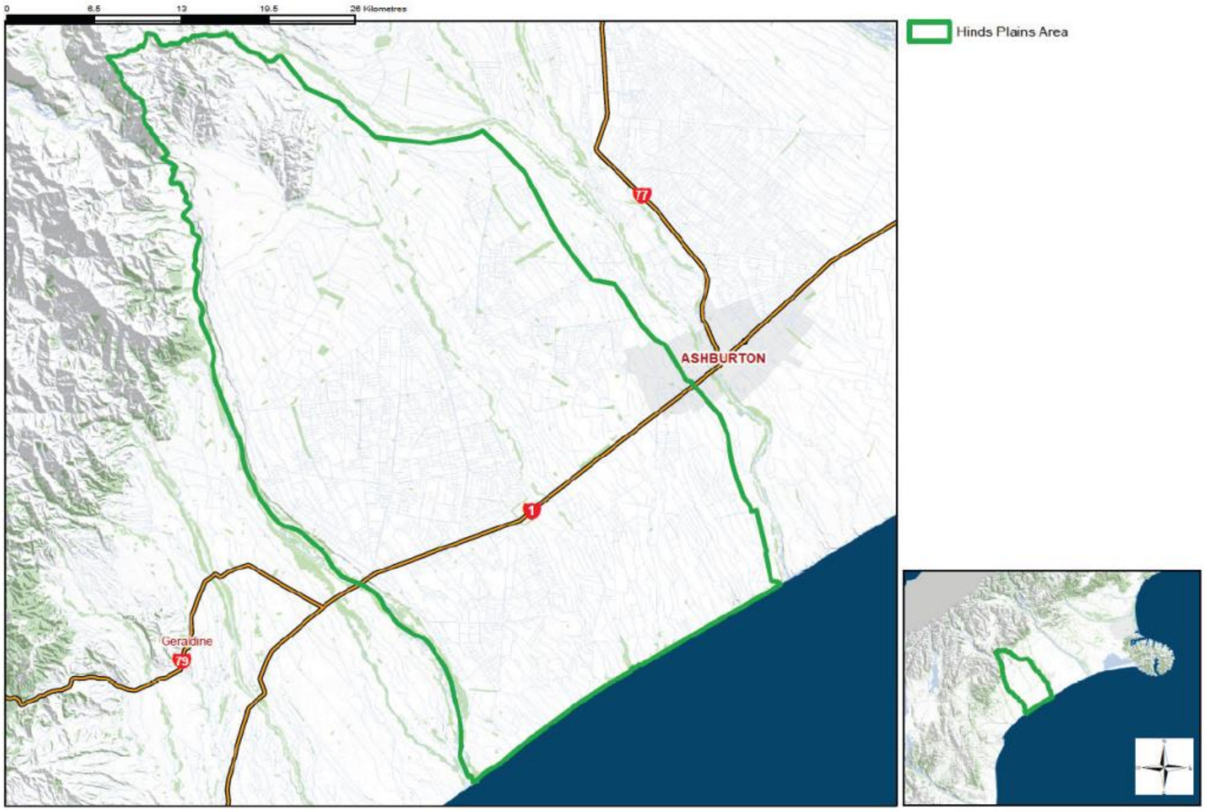


Figure 9: Boundary of the Hinds/Hekeao Plains area in the Ashburton Zone (Source: Environment Canterbury, 2014*b*).

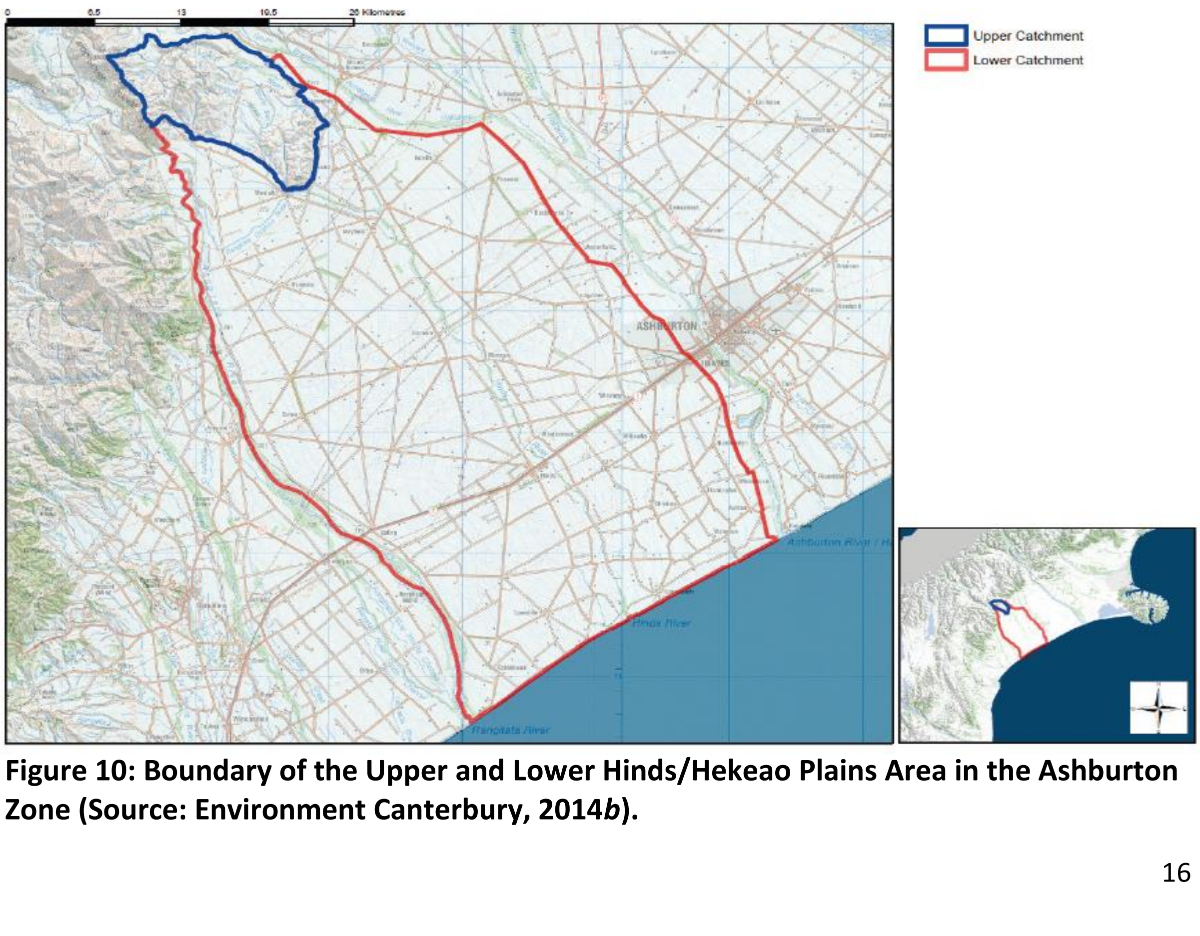


Figure 10: Boundary of the Upper and Lower Hinds/Hekeao Plains Area in the Ashburton Zone (Source: Environment Canterbury, 2014*b*).

1.6.5. Land and Water Regional Plan's Region-Wide Rules

The region wide rules are similar to the Hinds/Hekeao Plains Area, particularly for farms that are located in the Red Nutrient Allocation Zone (see Figure 11). Red Nutrient Allocation Zones are classified as areas where water quality standards are not met (Environment Canterbury, 2013). Farms within the Red Nutrient Allocation Zone are not allowed to exceed their nitrogen baseline if their nitrogen losses are greater than 20 kg per hectare per year (Environment Canterbury, 2013). However, from the 1st of January 2017, if farmers do not meet these conditions a FEP needs to be prepared (Environment Canterbury, 2013). During this time farms will also require resource consent to farm (Environment Canterbury, 2013).

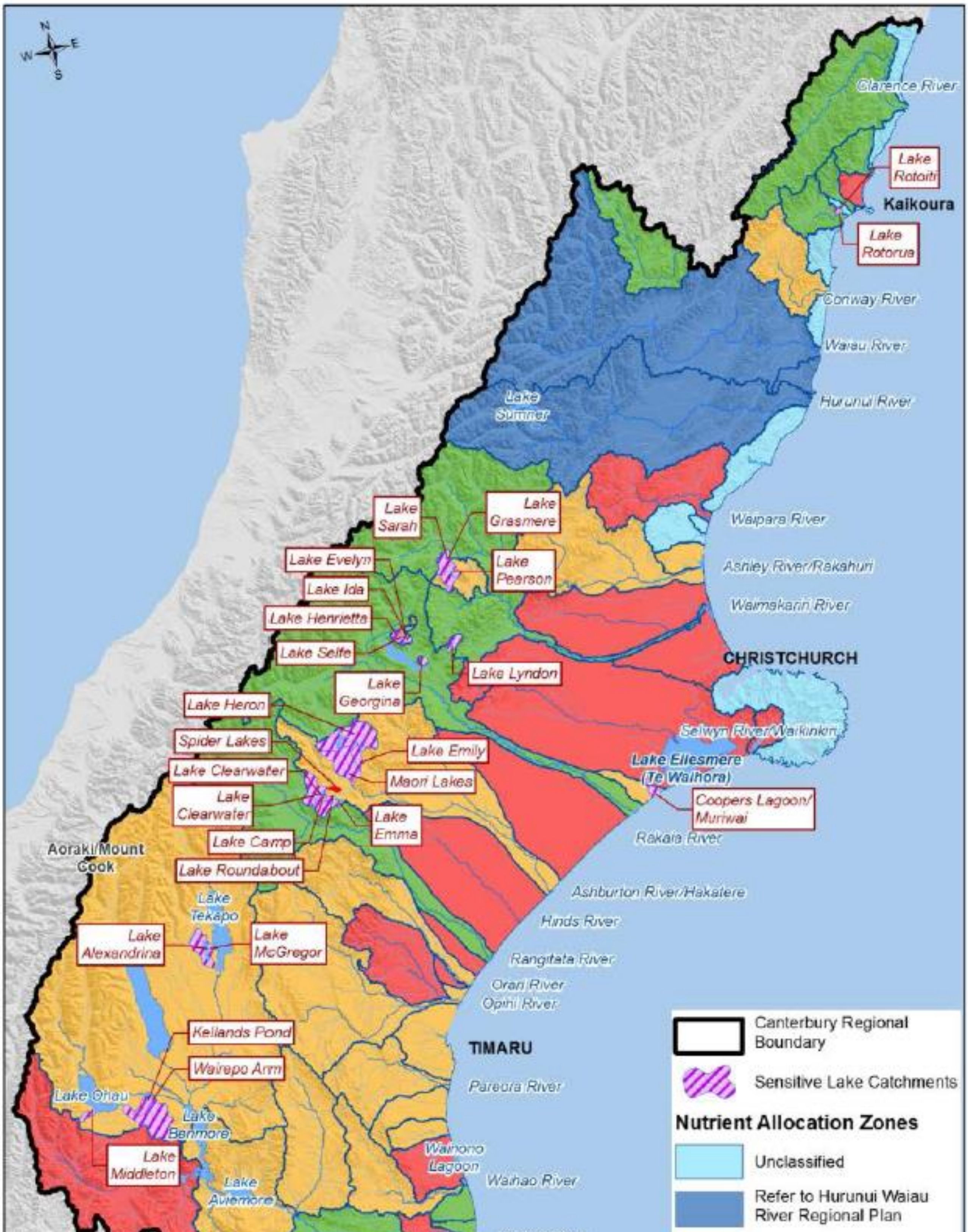


Figure 11: Nutrient Allocation Zone in the Canterbury region (Source: Environment Canterbury, 2013).

1.7. Future of Land and Nitrate Use

It is likely that rapid land use intensification will continue to occur (PCE, 2013). Figure 12 shows how different land uses have changed over the last 12 years as well as predictions for future land use (PCE, 2013).

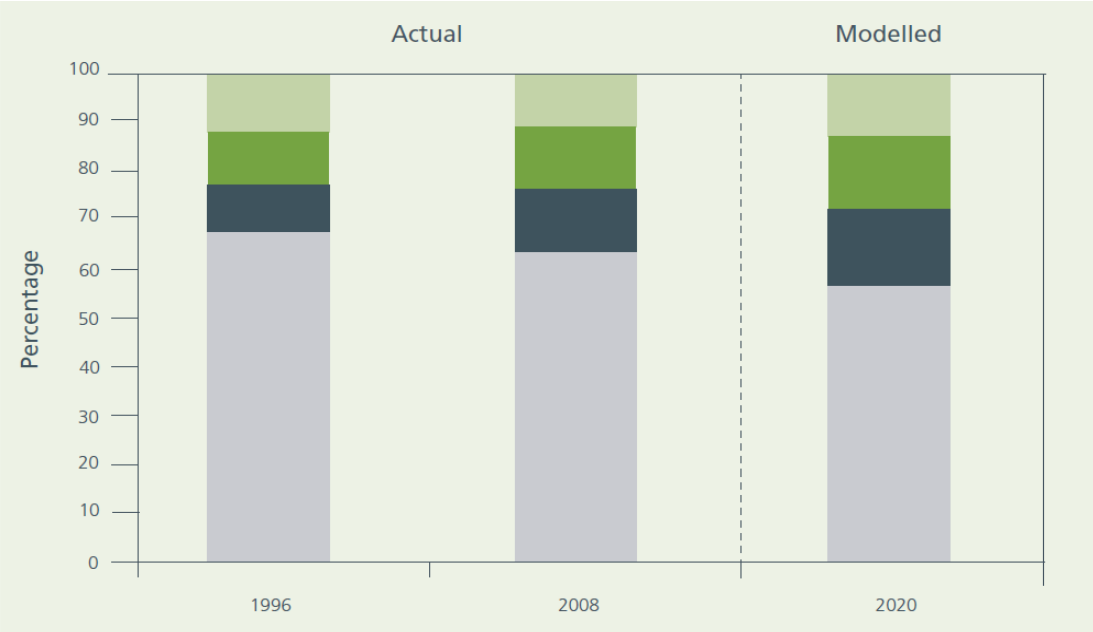


Figure 12: Past and Future Trends and Predictions for Land Use in New Zealand (light grey = sheep/beef farms, dark grey = dairy farms, dark green = plantation forest, light green = scrubland) (Source: PCE, 2013).

However, with the fluctuations in supply and demand for New Zealand's exports, it is difficult to predict what farming operations will increase in the future. Although the dairy pay-out is significantly low at present due to reduced overseas demand, dairy farming is likely to increase in New Zealand. Comparatively the number of sheep and beef farms will decrease due to dairy expansion.

Land use increase is inevitable and it is likely that nitrate concentrations will also increase because there is a direct relationship between these two variables.

1.8. Research Aims & Objectives

The purpose of this research was to determine whether irrigation groundwater could potentially be used to partially replace nitrogen inputs from fertilisers to both reduce the amount of nitrogen that is present in groundwater and reduce fertiliser application. Essentially farmers would be recycling their nitrogen application from groundwater back onto agricultural land. The research is focused in the Selwyn and Ashburton Districts where there are high nitrogen concentrations in the groundwater and farmers mostly rely on this groundwater for irrigation. Therefore, the groundwater contribution to these farms is likely to be significant. It is hoped that with the implementation of nutrient limits in these districts, the results of this research could be beneficial for nitrogen management on farms.

This research had the following objectives;

1. To select 16 farms in the Selwyn and Ashburton Districts that use groundwater for irrigation and have a significant nitrogen input;
2. To obtain good quality data for each farm’s nitrogen input, irrigation application rate, nitrogen concentrations in groundwater and soil type;
3. To quantify the addition of nitrogen from groundwater to agricultural land using a nutrient load calculation;
4. To compare the nutrient load calculations for each farm to the current application rate of nitrogen fertiliser to agricultural land. Nutrient budgets will also be produced by the nutrient modelling programme OVERSEER® to compare to nutrient limits set in each district; and
5. To make recommendations to the farmers that participated in the research on how to best manage nitrogen on farm.

2. Methods

This research involved identifying farmers that record high quality data for their farm and who were willing to participate in this study. Farm data including irrigation and nitrogen fertiliser application rate, NO_3-N concentrations and soil type were collected from these farmers. This data was analysed to calculate the nitrogen contribution from groundwater to each farm. OVERSEER® was used to produce nutrient budgets and to make recommendations for each farm on their nutrient management.

2.1. Farm Selection Process

Farmers located in the Selwyn and Ashburton Districts were chosen to participate in this research. As shown on Figure 13, the Selwyn District is situated between the Waimakariri and Rakaia Rivers while the Ashburton District is situated between the Rakaia and Rangitata Rivers. Both of the districts were split up into upper and lower catchments to include different farming types, soils types and to provide an unbiased representation of the area. For both districts the upper catchment included farms that were west of State Highway One while to the east of this included farms in the lower catchment. Within these districts are multiple groundwater zones that are over allocated or close to being fully allocated as classified by ECan.

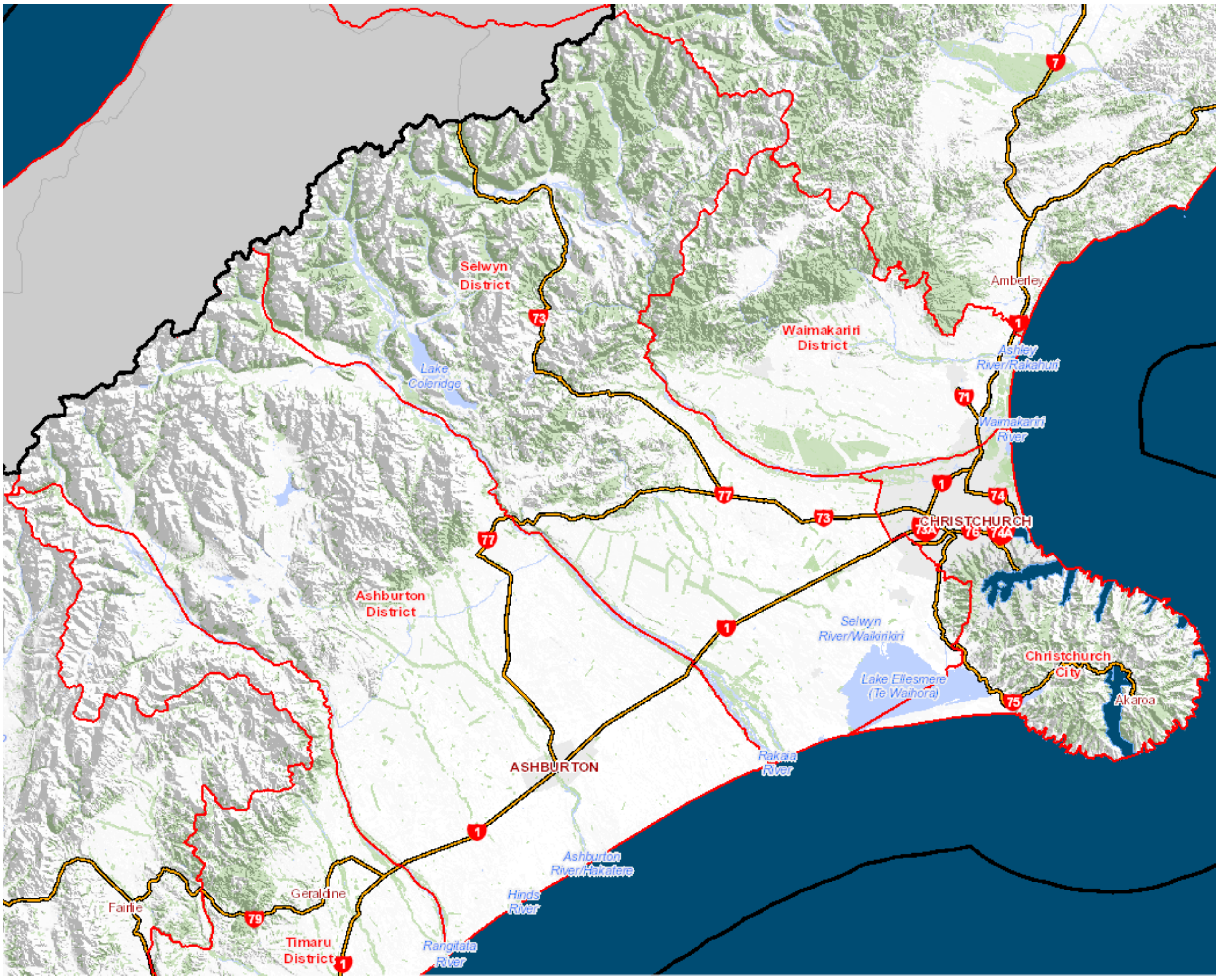


Figure 13: Map of the research area including the Selwyn & Ashburton Districts (Source: Canterbury Maps, 2014).

In the upper catchment of the Selwyn District, the soils are light which allows for nutrients such as nitrogen to easily leach through to the groundwater (Sunckell, 2014). However, in the lower catchment the soils are more dense and heavy, suggesting that it is more difficult for water to percolate (Sunckell, 2014). The lower catchment also experiences water drainage issues due to soil type. The soils in Ashburton commonly consist of stony silt loams that are relatively free draining soil with little water holding capacity (Hanson & Abraham, 2010).

The main criterion for farm selection was the use of groundwater for irrigation. It was easier to select farmers within the Selwyn District as the Central Plains Water irrigation scheme is the only main surface water source in the area. This scheme began providing farmers with surface water at the start of the 2015/2016 irrigation season. However, in the Ashburton District there are seven different irrigation schemes using surface water and the majority of them provide water to farms situated in the Ashburton upper catchment (Irrigation New Zealand, 2015). Therefore, it was difficult selecting farmers that source water only from groundwater in the upper Ashburton District. Consequently, most farmers participating in this research from the Ashburton District were located in the lower catchment.

Farms were also selected based on nitrogen load input and their subjectivity to the recent nutrient limits set in the LWRP. Therefore, dairy and arable farms were the most suitable for this research as they are the main users of nitrogen fertilisers. These farmers will also be subjected to the LWRP's nutrient limits as they are all located in a Red Nutrient Allocation Zone.

These farms were drawn from personal contacts and included farmers who have a particular interest in farm advising, innovative farming, improving the environment and have won awards for farming. As the information that was obtained from farmers is private, a human ethics application was made to the University of Canterbury's Human Ethics Committee to ensure participant protection and this application was accepted on March 26, 2015. For this application an information sheet and consent form was developed to inform farmers of the research aims, the information that was required from them and how the information found would be beneficial. The consent form also outlined what was required of the farmer and informed them on how the data would be used, protected and published. All of the farmers that participated in this research chose to remain anonymous and keep their data private. Therefore, farms are identified using codes throughout this thesis. Farmers were given a time frame of a month to two months to return the data requested. This data was returned either via email or in person during farm visits.

2.1.1. Description of Farms

Nine farms in the Selwyn District and another seven in the Ashburton District were chosen to participate in this research. Of the 16 farms, 13 were dairy farms and three were cropping farms with some stock. Most of these farms primarily use groundwater for all irrigation, except two that used both groundwater and surface water together. Irrigation seasons for these farms were also similar, occurring from October to April depending on the climate during the season. The key aspects of all these farms are summarised in Table 1.

Upper Selwyn District Farms:

Farm A

Farm A is a 181 hectare dairy farm than runs 695 cows during peak milking, producing 245,000 kilograms of milk solids per year. A centre pivot is used for irrigation and waters approximately 140 hectares of the farm while the rest of the area is irrigated by sprinklers and roto-rainers. Water is sourced from two groundwater wells that are 230 to 240 metres deep. Overall, the farm has a low environmental impact as they implement management practices to reduce adverse effects. This includes riparian strips to decrease the amount of run-off that enters surface waterways, the spreading of effluent over an adequate area to ensure nutrients are consumed by pasture growth and the farm also uses soil moisture monitoring technology to determine when and how much water should be applied.

Farm B

Farm B is a 173 hectare dairy farm that in the 2013/2014 season milked 571 cows, producing 217,086 kilograms of milk solids from a 40 bale herringbone cowshed. The farm was converted to dairy in 2007. A centre pivot is used for irrigation and is centrally located watering in one pivot. Irrigation water is sourced from a well that is 105.83 metres deep. Aquaflex is also used to measure soil moisture and is able to indicate when irrigation is required. An average rainfall of 718 millimetres is also received on farm.

Figure 14: Groundwater well at Farm B.

Farm C

Farm C is a 133 hectare dairy farm that in the 2013/2014 season milked 550 cows, producing 209,971 kilograms of milk solids from a 38 bale herringbone cowshed. This farm was previously a deer farm and was converted in 2004. The farm is only partly irrigated by three roto-rainers. The water is sourced from bores that range from 125 metres to 130 metres in depth. The rest of the land is mostly dryland and is used for dairy support, growing crops and wintering cows. However, the Central Plains Water irrigation scheme has allowed land to be irrigated and the farm is currently "re-converting" where new centre pivots and a larger rotary cowshed is being constructed. Therefore, for the farms 2015/2016 season, the main irrigation water source will be surface water.

Figure 15: Groundwater well at Farm C.

Figure 16: New centre pivot on Farm C.

Farm D

Farm D is a 268 hectare dairy farm that in the 2013/2014 season milked 893 cows and produced 306,145 kilograms of milk solids from a 50 bale rotary cowshed. One centre pivot is used for irrigation and approximately 257 hectares is effectively watered. The pivot is centrally located next to the dairy shed which allows the entire farm to be irrigated in one full pivot. Irrigation water is sourced from a well that is 233.5 metres in depth. This farm also uses soil moisture monitoring technology and receives an average of 729 millimetres per year.

Figure 17: Groundwater well at Farm D.

Lower Selwyn District Farms:

Farm E

Farm E is a 160 hectare dairy farm that in the 2013/2014 season produced 276,019 kilograms of milk solids from 630 cows. The farm was previously sheep and cropping with limited irrigation. It was converted to dairy for the 2001/2002 milking season. A centre pivot is used to irrigate 127 hectares while laterals, K-Line and a hose gun are used to irrigate areas that the pivot does not reach. Most of the soils are imperfectly drained and the farm receives an average annual rainfall of 666 millimetres. Groundwater that is used for irrigation is sourced from a well that is 90 metres deep. Aquaflex is also used on this farm to provide information on soil moisture to increase water use efficiency.

This farm is also part of Fonterra's Nitrogen Management Programme which allows farmers to work towards reducing nitrogen losses while still retaining profitability. This programme helps determine where the largest nitrogen losses are on the farm and how these could be better managed.

Farm F

Farm F is a dairy farm that was first converted in the mid-1980's and had approximately 200 to 300 cows. Now the farm has 650 cows that are milked in a herringbone cowshed and produces 220,000 kilograms of milk solids per season on average. The farm has an effective irrigated area of 195 hectares and uses four centre pivots, one roto-rainer, a gun and K-Line. Groundwater is pumped from a well that is 68 metres deep. The soils are light and poorly drained which can cause higher leaching rates.

The nitrogen input is kept relatively low with significant management and planning being put into reducing nitrogen losses. The farm is also part of Fonterra's Nitrogen Management Programme.

Figure 18: Groundwater well at Farm F.

Farm G

Farm G is a 129 hectare dairy farm that produced 235,581 kilograms of milk solids in the 2013/2014 season from 510 cows. These cows are milked in a 60 bale rotary cowshed. The farm was converted to dairy in 2009 and the owner previously used the farm for dairy support when it was bought in 2005. Before it was owned by the current farmer, it was extensively farmed as part of a sheep operation and had relatively low phosphorous and pH levels. Approximately 116 hectares of the farm is effectively irrigated by a centre pivot. There is also 11 hectares of fixed grid irrigation next to the water storage pond. This farm is one of the two farms that have resource consent to take water from groundwater as well as surface water. This water is stored in a irrigation pond situated on the farm. Groundwater is sourced from a depth of 100 metres as part of consent requirements. The farm receives approximately 625 millimetres of rain per year.

Figure 19: Storage pond for irrigation on Farm G.

Farm H

Farm H is a 221 hectare dairy farm that milks around 670 cows and produces 290,000 kilograms of milk solids on average. Before the farm was converted, it was a traditional dryland beef farm that had low nitrogen inputs and outputs. The farm was converted in 1994 and along with this the irrigation infrastructure was upgraded to centre pivots, roto-rainers and K-Line. The centre pivot effectively irrigates 114 hectares of the farm while the roto-rainers irrigate 84 hectares and the G-set sprinklers water 16 hectares. Groundwater is sourced from three bores that have a depth between 36 and 75 metres. The farm receives an annual rainfall of 650 millimetres.

Figure 20: Groundwater well at Farm H.

Farm I

The farm has a total area of 610 hectares which is separated into five different blocks that consist primarily of mixed cropping with some stock. Three of these blocks will be used throughout this research and are mainly irrigated using centre pivots, laterals and roto-rainers. These three blocks have a total irrigated area of 186 hectares. Irrigation water for these blocks is sourced from three separate wells that are 10.5, 12.5 and 18.2 metres in depth.

Over the last five years, there have been various crops rotated though the blocks which include: pasture, peas, wheat, barley, clover, ryegrass, and browntop. The farm also uses soil moisture monitoring technology to for irrigation management.

Upper Ashburton District:

Farm J

Farm J is a 171 hectare dairy farm that in the 2013/2014 season milked around 708 cows and produced 1920 kilograms of milk solids per hectare. This farm was converted from a cropping farm in July 2012 and the irrigation systems have since been upgraded from laterals to centre pivots with some sprinklers. Therefore, only three seasons of data were available for analysis. Irrigation water is sourced from a well that has a depth of 11 metres.

This farm is also part of Fonterra’s Nitrogen Management Programme and the farm works towards effectively managing nitrogen losses.

Farm J is the only farm in the Upper Ashburton District used for this research due to the numerous irrigation schemes in this catchment.

Lower Ashburton District:

Farm K

Farm K is a mixed cropping farm that has only been operating for one season (2014 to 2015) as it has recently been purchased by its current owner. The farm is 468 hectares in total and only 430 hectares are irrigated. There are two pivots and four laterals that are used for irrigation and water is sourced from both groundwater (50 percent) and surface water (50 percent) via an irrigation scheme (see Figures 21 and 22). This water is pumped into a storage pond that is located on the farm. The farm consists of crops including: potatoes, wheat, grass seed, clover, fodder crops, peas, maize, barely, pasture and canola. There is also some stock on the farm including lambs and dairy cows that are wintered on fodder beet.

Figure 21: Irrigation pond where groundwater and surface water is stored on Farm K.

Figure 22: Irrigation scheme water (surface water) that is pumped into irrigation pond on Farm K.

Farm L

Farm L is a 480 hectare dairy farm that milks around 2,350 cows in an 80 bale rotary cowshed and produces 1700 kilograms of milk solids per hectare on average per season. The farm was originally converted to dairy in the 2006/2007 season and has since then added an additional 40 hectares which has allowed increased cow numbers. The farm is fully irrigated with two centre pivots, four roto-rainers and 60 sprinklers. Groundwater is sourced from wells that are 70 metres deep. This farm is also a part of Fonterra's Nitrogen Management Programme.

Due to the farms close proximity to a neighbouring meat processing factory, NO_3-N concentrations in the groundwater are monitored regularly. This monitoring is likely undertaken to ensure that the NO_3-N concentrations do not exceed the NZDWS of 11.3mg/L.

Farm M

Farm M is a 210 hectare dairy farm that in the 2014/2015 season milked 752 cows and produced 350,000 kilograms of milk solids. There is approximately 195 hectares in total irrigated by three centre pivots. Irrigation water is sourced from a well that has a depth of 61.96 metres. This farm is also located on a swamp which influences water holding capacity.

Figure 23: Centre pivot used for irrigation on Farm M.

Farm N

Farm N is a 303 hectare dairy farm that was converted in 2009 from a mixed cropping farm. In the 2013/2014 season the farm milked 1,069 cows and produced 410,352 kilograms of milks solids from a 60 bale rotary dairy shed. The farm is irrigated by three centre pivots that source water from three shallow wells (See Figure 24). The wells vary in depths between 43 and 50 metres.

This farm is also located within close proximity to the coastline and as part of their resource consent they must monitor conductivity to ensure they are not pumping saline seawater.

Figure 24: One of the three groundwater wells on Farm N.

Farm O

Farm O is a 238 hectare dairy farm which during peak milk produces 413,000 kilograms of milk solids per season from 920 cows in a 60 bale rotary cowshed. This farm was converted four years ago from a cropping, beef and limited sheep farm. Approximately 230 hectares are effectively irrigated by centre pivots and sprinklers. The farm sources groundwater from three bores that not only provide water for irrigation purposes but also for domestic and dairy shed use. Bore 1 is 45 metres deep, Bore 2 is 50 metres deep and Bore 3 is 60 metres deep. This farm is also part of the Fonterra's Nitrogen Management Programme.

Due to data collection constraints, the farmer was only able to provide two years of data.

Figure 25: One of the groundwater wells at Farm O.

Farm P

Farm P is a cropping farm and has a total of 163 hectares. The farm has resource consent to take both groundwater and surface water. However, majority of irrigation water is sourced from groundwater as it is a more reliable source. In the 2014/2015 season, no surface water was abstracted as the source went dry due to the harsh climate conditions. The groundwater well is 84 metres deep and another well is currently being drilled to use as another source of water for irrigation. Two large guns are primarily used for irrigation on this farm and water is pumped at 25 litres per second if surface water is on restriction. There are also tile drains that are situated throughout the farm.

There is a mixture of crops that are grown and these vary from season to season. These crops include: pasture (for stock), barely, browntop, ryegrass, turnips, wheat, raddish and kale.

Table 1: Summary of key aspects for each farm chosen to participate in the research (N/A = Not Applicable, GW = Groundwater, SW = Surface Water).

Catchment	Farm	Farm Type	Annual Milksolids Produced (kg/MS/year)	Total Area Irrigated (hectares)	Year Converted (Dairy Only)	Irrigation Water Source	Well Depth (metres)
Upper Selwyn District	Farm A	Dairy	245,000 from 695 cows	181	2003	GW	230-240
	Farm B	Dairy	217,086 from 571 cows	173	2007	GW	105.83
	Farm C	Dairy	209,971 from 550 cows	133	2004	GW	125-130
	Farm D	Dairy	306,145 from 893 cows	257	N/A	GW	233.5
Lower Selwyn District	Farm E	Dairy	276,019 from 630 cows	127	2001	GW	90
	Farm F	Dairy	220,000 from 650 cows	195	mid-1980	GW	68
	Farm G	Dairy	235,581 from 510 cows	127	2009	GW & SW	100
	Farm H	Dairy	290,000 from 670 cows	214	1994	GW	36-75
	Farm I	Arable	N/A	178	N/A	GW	10.5-18.2
Upper Ashburton District	Farm J	Dairy	328,320 from 708 cows	171	2012	GW	11
Lower Ashburton District	Farm K	Arable	N/A	430	N/A	GW & SW	80
	Farm L	Dairy	816,000 from 2350 cows	480	2006	GW	70
	Farm M	Dairy	350,000 from 752 cows	195	N/A	GW	60.96
	Farm N	Dairy	410,352 from 1069 cows	303	2009	GW	50
	Farm O	Dairy	413,000 from 920 cows	230	2011	GW	45-60
	Farm P	Arable	N/A	163	N/A	GW + limited SW	84

2.2. Data Collection from Farmers

Data was collected from farmers either in person, through email or over phone. This included informal interviews with farmers to establish a better rapport with them and to understand how the farm works. Appendix 3 shows the data request form given to farmers during the data collection process. The data request form also included an explanation on the type of data required.

Farmers were asked to provide the data for the last five years. This allowed an average to be established, to allow for any climatic variability that had occurred. It is likely that annual irrigation application rates would have changed over the five years, particularly during the 2014/2015 irrigation season as farmers experienced drought-like conditions. However, as farmers have only been required by ECan to meter their water since 2011, it was not possible to get this data for the last five years in some cases. Therefore, farmers were asked to supply information that was available.

Farmers selected were the main data sources and were asked to provide data on their groundwater NO_3-N concentrations, irrigation application and nitrogen application as well as basic farm information (i.e. size of farm, soil information, crop types, and number of cows). This data is explained further below.

2.2.1. Annual Irrigation Application Rate (AIAR)

The AIAR was the volume of water abstracted during each of the past five year's irrigation seasons. Farmers all had meters that record the amount of water used and are able to access this data from an online database. Irrigation data was provided either in cubic metres (m^3) or millimetres (mm) applied to the land.

2.2.2. Annual Nitrogen Input onto Agricultural Land

Nitrogen fertilisers are one of the most predominant nitrogen inputs onto farms and this includes common fertilisers such as urea. Fertiliser companies can often provide end of season reports that indicate fertiliser type and amount used. There are also programmes including 'Precision Tracking' where monthly fertiliser data use can be entered into an online database and annual reports produced. The fertiliser application data was commonly given in either kilograms per hectare per year (kg/ha/year) or in tonnes.

2.2.3. Farm Size

This data included the total size of the farm which is commonly measured in hectares. Farmers were also asked if they could provide the size of land effectively irrigated as some areas are often missed by irrigators or are left as dryland.

2.2.4. Information on Soil Type

Farmers were asked to provide any data on the soil type. This included information on soil permeability, soil water holding capacity, density, leaching rates, soil type and soil temperature as well as any soil maps. This information was used to help determine why particular nitrogen losses were experienced on each farm. Soil information was also obtained from the digital soil database 'S-Maps' which was developed by Landcare Research (Landcare Research Limited New Zealand, 2016).

Soil types vary immensely along the Canterbury Plains which results in different leaching rates on farms and this becomes important when working with OVERSEER®.

2.2.5. Groundwater Nitrogen Concentrations

Few farmers were able to provide data on nitrogen concentrations in their groundwater. Farms B, C, D, L and N have to monitor their NO_3-N concentrations as part of conditions in their resource consent so were able to provide this data for some years.

If there was no available information on NO_3-N concentrations, a groundwater well sample was taken, when given permission by the farmer. These samples were collected monthly for all farms over a time frame of six month to eight months to allow for possible seasonal changes in concentrations.

Groundwater Sampling Process

Groundwater samples were collected from either the well head or tap connected to the groundwater. To limit contamination, the tubes used to collect water were new 50ml centrifuge tubes. Groundwater samples were filtered through 0.45µm membranes in the field and samples were stored on ice until analysed. Analysis was completed within 24 hours of the sample being taken. However, if this was not possible due to time constraints, the samples were frozen until they were able to be analysed.

The groundwater samples were analysed for NO_3-N either in the field or in the Waterways Laboratory at Lincoln University. This consisted of using a HACH DR90 spectrophotometer to measure NO_3-N concentrations in the groundwater from each sample. For each sample, 10 millimetres was transferred into four separate cuvettes. Contents of one HACH NitraVer 5 Nitrate Reagent Pillow Pocket were then added to three samples, while the other one was left as a blank sample with no reagent. The cuvettes were then closed and the three samples were shaken vigorously for one minute using the timer on the spectrophotometer to dissolve the reagent powder. Any powder that did not dissolve usually would not affect the results. The samples were then left to sit for five minutes, and depending on the NO_3-N concentration in the water an amber colour would begin to develop. A stronger amber colour indicated that the NO_3-N concentration would be high. Before being put into a HACH DR90 spectrometer, the glass cuvettes were wiped with a paper towel to ensure that no fingerprints or dirt affected the results. The blank sample was used to zero the spectrophotometer before measuring the other three samples. The three samples were then put into the spectrophotometer to read their concentrations and from the three concentrations that were recorded, an average was determined. The sample was then disposed of safely and the cuvettes were rinsed before testing other samples. The calibration relating absorbance to concentrations was that of the HACH spectrophotometer.

Figure 26: Testing for NO_3-N in the field.

2.2.6. Measurement of Other Water Parameters

A HACH 40D multimeter was also used to measure temperature, pH, conductivity and dissolved oxygen of groundwater. Before going into the field the meters were calibrated and cleaned from previous use to avoid contamination. By measuring all these components a better understanding of the groundwater conditions was made.

Conductivity

Conductivity measurements indicate the ability of an electrical current to pass through the water, and depend on the concentration of dissolved ions present (Greenberg, Clesceri, & Eaton, 1992). The conductivity probe was attached to a HACH 40D mulitmeter, and a value was recorded once stabilised. Conductivity was measured in microsiemens (µS/cm).

Figure 27: Testing water parameters in the field using a HACH 40D multimeter.

pH

A pH scale was used to measure the acidity or alkalinity of water and results range from 0 (acidic) through to 14 (alkaline). Most freshwater environments will have a pH between 6.5 and 8.0 (ANZECC, 2000). To measure this a pH probe on a HACH 40D multimeter was placed in the water and left to stabilise before the result was recorded.

Dissolved Oxygen

Dissolved oxygen measures the amount of oxygen that is dissolved in the water as either a percentage saturation or milligram per litre. Percentage saturation is determined as a percent of the amount of dissolved oxygen expected to be in the water for that particular water sample if it was fully saturated with oxygen. To measure dissolved oxygen the probe on a HACH 40D multimeter, was placed in the water until it stabilised and dissolved oxygen was measured in milligrams per litre (mg/L).

Water Temperature

While measuring conductivity, pH and dissolved oxygen of the water, the probes were also able to read the temperature. For groundwater it is likely that colder temperatures are usually associated with increasing well depths.

2.3. Data Analysis

2.3.1. Nutrient Load Calculations

The data gathered was analysed using Microsoft Excel to calculate the amount of NO_3-N that is applied via irrigation from groundwater. The annual irrigation application rate and the average groundwater NO_3-N concentrations were used to determine NO_3-N contribution applied through irrigation for each season per farm. The data provided by the farmers was firstly converted into suitable units before using the below equation to calculate the nutrient load.

Example of Nutrient Load Equation:

$$\text{Load (mg/sec)} = \text{flow (L/sec)} \times \text{concentration (mg/L)}$$

The results from the calculations were converted into kg/ha/year so they could be compared to total annual nitrogen input (i.e. nitrogen fertiliser application) for each farm. These nutrient loads were also compared to the nutrient limits in the LWRP.

2.3.2. OVERSEER® Nutrient Budgets

OVERSEER® is a modelling programme that produces farm nutrient budgets based on data input from different farming types and was used for some of the farms in this study. The OVERSEER® programme is owned by the New Zealand Ministry for Primary Industries, the Fertiliser Association of New Zealand and AgResearch Limited and is available to download from the OVERSEER® website. The most recent version (Version 6.2.1) was used for the duration of this research as this version allows farmers to input their irrigation data including the irrigation type, the amount of nutrients added from irrigation water and how farmers schedule irrigation. OVERSEER® training was provided by Micheal Keaney, a Science Extension Specialist for the fertiliser company Ballance Agri Nutrients. A day-long beginner training course was also attended which was ran by AgResearch OVERSEER® developer Natalie Watkins.

Since the participating farmers were all relatively busy with work related to their farm, the farm data that OVERSEER® requires was obtained from fertiliser companies and a dairy company. These companies often produce the nutrient budgets as part of a service they provide to their shareholders. The fertiliser companies, Ravensdown and Balance Agri Nutrients, and the dairy company, Fonterra, were able to provide OVERSEER® files for all of the dairy farms (apart from Farm M) that were used for this research. These OVERSEER® files had all of the farm data and assumptions that were made to produce nutrient budgets. Once the files were received, they were imported into OVERSEER® where they were used in the analysis to determine how nitrogen losses changed by using default data in comparison to actual measured data.

The cropping farms proved to be the most difficult to produce nutrient budgets for, due to the various crop rotations that annually occur. Only one cropping farm (Farm K) had already produced a nutrient budget and was used in this research. While due to time constraints and the unknown accuracy of using OVERSEER® for cropping farms, no nutrient budgets were produced for Farm I and P.

Three different scenarios were run through OVERSEER® to compare how significant the changes in nitrogen losses were. The scenarios are described below:

Scenario 1:

This scenario involved the original farm data and the OVERSEER® default concentration for the amount of NO_3-N as well as the other nutrients added to land from irrigation water. The NO_3-N default value has a fixed concentration of 2.5mg/L in irrigation water as shown on Figure 28.

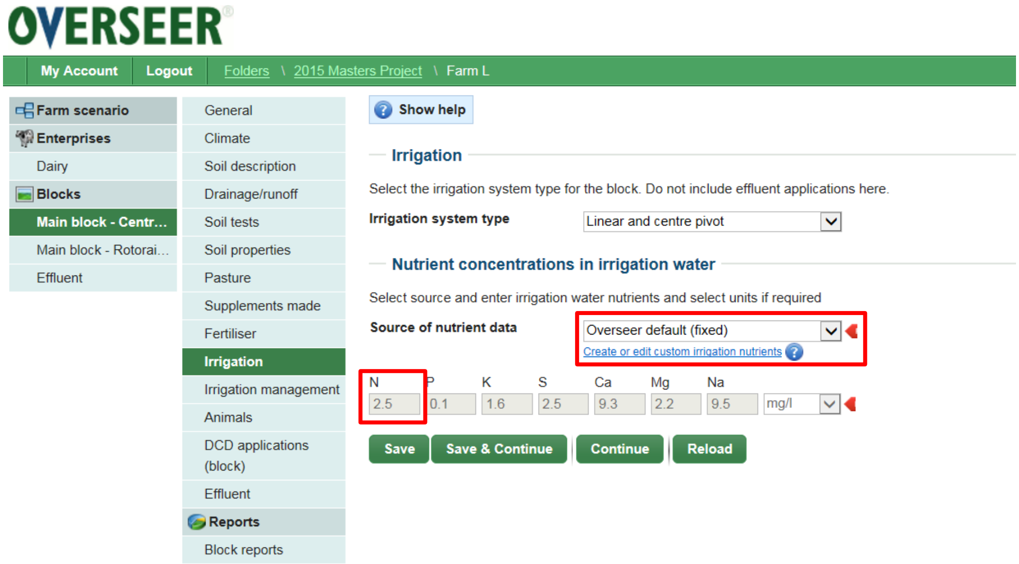


Figure 28: Default NO_3-N Concentrations in OVERSEER® (Red boxes indicate default setting and value) (Source: OVERSEER® 2015).

Scenario 2:

This scenario uses the same farm data but the default NO_3-N concentrations in OVERSEER® were instead changed to the actual measured concentrations on each farm (see Figure 29). The other nutrient concentrations in OVERSEER® were kept as the same default value.

Scenario 3:

This scenario included the actual NO_3-N concentrations measured for each farm. Although all of the farm data was still used, the nutrient load that was calculated for each farm's nitrogen groundwater contribution was subtracted from their annual nitrogen fertiliser application rate.

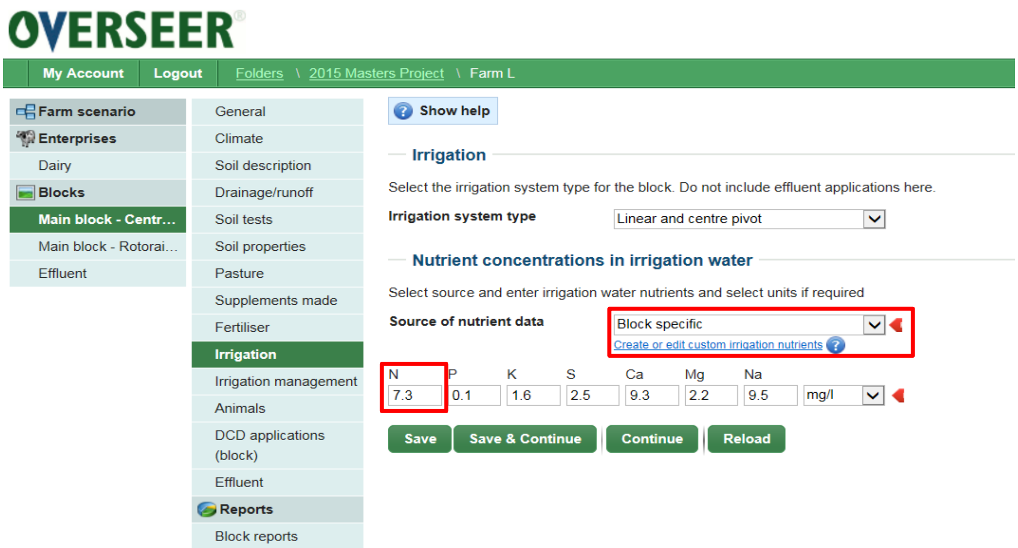


Figure 29: Actual NO_3-N concentrations measured on farm used in OVERSEER® (Red boxes indicate change to actual measured NO_3-N concentration) (Source: OVERSEER® 2015).

2.4. Recommendations for Farmers

For the farmers that participated in this research, a short report was produced that explained how the data they provided was used and the results found. Farmers were able to get a better insight into their nitrogen losses and may use this information to help meet nutrient limits set in the LWRP and in their FEPs. This information can be used by farmers as they wish and there are no obligations regarding how or if they use it.

3. Results

3.1. Compilation of Farm Data

3.1.1. Annual Irrigation Application Rate

Table 2 shows the groundwater amount used to irrigate each farm over the last five seasons. These irrigation application rates vary depending on the farm size, soil type, crop/pasture requirements and climate. Farm L used the most groundwater on average over the last five years as it is the largest farm while Farm P used the least amount of groundwater.

The 2014/2015 irrigation season was significantly drier than previous seasons and this is shown on Table 2 as more water was applied on each farm within this season. However, the results from the 2011/2012 irrigation season suggest that more rainfall periods occurred as less water was applied, in comparison to other seasons.

The cropping farms, Farm I and P, also had some years where irrigation was not necessary as crops may have been able to cope without water. Farms A and H were unable to provide irrigation data for some years due to water meters failing to record consumption. Therefore, where farms were not able to provide data for all five seasons, a five year average was determined based on the data provided.

3.1.2. Annual Nitrogen Input into Agricultural Land

Table 3 shows the amount of nitrogen fertiliser applied to each farm. Fertiliser application ranged from 57 kg/ha/year to 310 kg/ha/year and it was expected that the amount applied increased when land size was larger. Nitrogen fertiliser application for majority of the farms did not vary significantly and application was consistent over the five years. Both Farm A and J applied the exact same amount within the five year period. Most farmers commented that they applied fertiliser in the most efficient way depending on pasture/crop growth. In Section 3.4 this nitrogen fertiliser data was used to compare to the NO_3-N contributed to each farm by groundwater irrigation.

When fertiliser application data could not be provided for all five seasons, a five year average was calculated based on the data provided.

Table 2: Annual irrigation application rate to agricultural land (ND = No Data Available, ID = Incomplete Data, NIA = No Irrigation Applied).

Farm:	Annual Irrigation Application Rate (m^3/year)					
	2014/2015	2013/2014	2012/2013	2011/2012	2010/2011	**5 Year Average**
Farm A	727,620	414,060	611,040	ID	ID	**584,240**
Farm B	918,902	517,312	815,158	686,894	873,770	**762,407**
Farm C	710,378	594,213	657,840	487,919	653,084	**620,687**
Farm D	1,606,334	1,033,989	1,326,993	942,027	1,376,939	**1,257,256**
Farm E	800,000	800,000	889,600	499,200	1,011,520	**800,064**
Farm F	947,213	862,956	750,000	750,000	750,000	**812,034**
Farm G	756,015	ND	ND	ND	ND	**756015**
Farm H	1,463,954	789,332	1,290,803	ID	ND	**1,181,363**
Farm I (Block 1)	82,650	38,783	54,133	19,383	66,633	**52,317**
Farm I (Block 2)	42,425	17,200	37,050	37,850	48,700	**36,645**
Farm I (Block 3)	67,500	21,000	52,500	58,500	108,000	**61,500**
Farm J	947,711	862,956	905,334	905,334	905,334	**905,334**
Farm K	2,000,000	ND	ND	ND	ND	**2,000,000**
Farm L	3,890,422	3,890,422	3,890,422	3,890,422	3,890,422	**3,890,422**
Farm M	850,000	ND	ND	ND	ND	**850,000**
Farm N	2,808,718	1,015,796	1,390,131	1,122,320	783,865	**1,424,166**
Farm O	794,096	541,677	ND	ND	ND	**667,887**
Farm P	150,422	80,870	NIA	NIA	80,611	**103,968**

Table 3: Annual nitrogen fertiliser input to agricultural land (NDA = No Data Available).

Farm:	Annual Nitrogen Fertiliser Input (kg/ha/year)					
	2014/2015	2013/2014	2012/2013	2011/2012	2010/2011	**5 Year Average**
Farm A	300 ± 10	300 ± 10	300 ± 10	300 ± 10	300 ± 10	**300 ± 10**
Farm B	202	346	252	262	287	**270**
Farm C	165	181	263	318	362	**258**
Farm D	196	285	247	210	322	**252**
Farm E	143	242	351	354	325	**283**
Farm F	150	134	150	150	150	**147**
Farm G	249	261	248	200	253	**242**
Farm H	214	214	214	214	214	**214**
Farm I (Block 1)	160	163	196	61	206	**157**
Farm I (Block 2)	113	213	134	177	67	**141**
Farm I (Block 3)	57	61	86	66	78	**70**
Farm J	223	223	223	223	223	**223**
Farm K	174	NDA	NDA	NDA	NDA	**174**
Farm L	255	270	270	270	270	**267**
Farm M	225	NDA	NDA	NDA	NDA	**225**
Farm N	281	312	236	261	273	**273**
Farm O	230	230	NDA	NDA	NDA	**230**
Farm P	350	393	184	200	200	**265**

3.1.3. Information on Soil Type

Although some farmers were able to provide information on soil types, the data in Table 4 is mainly sourced from S-Maps (Landcare Research Limited New Zealand, 2016). This information was mostly used to determine leaching rates and in OVERSEER® nutrient budgets in Section 3.5.

While some farms only had one soil type, others had up to five different types. The Canterbury Plains commonly consist of a Lismore silty loam and this was the most common soil type as it was present on five out of the 16 farms. These soils are usually free draining and have a limited water holding capacity. The well-drained soils allow water to easily percolate through, minimising drainage issues. Poorly drained soils are more vulnerable to pugging at the surface and have a higher susceptibility to nitrogen loss (Landcare Research Limited New Zealand, 2016*a*).The water table in these soils are also higher which reduces the ability of water to filtrate through the soil profile (Landcare Research Limited New

Zealand, 2016*a*). Poorly drained soils have better water holding capacity compared to well drained soils and will cope better in drought conditions (Landcare Research Limited New Zealand, 2016*a*).

Table 4: Information on soil type for each monitored farm.

Farm:	Soil Type:
Farm A	Lismore silty loam (shallow, well drained)
Farm B	Lismore silty shallow loam (shallow, well drained)
Farm C	Lismore silty loam (shallow, well drained)
Farm D	Lismore silty loam (shallow, well drained)
Farm E	Wakauni silty loam over sandy loam (deep, imperfectly drained), Templeton silty loam (moderately deep, moderately well drained), Barhill loam over sandy loam (deep, well drained), Templeton sily loam (deep, moderately well drained)
Farm F	Leeston clay (shallow, poorly drained)
Farm G	Rangitata, Rakaia and Feredays stony silty loams (well drained)
Farm H	Eyre loam (shallow, well drained)
Farm I (Block 1)	Temuka silty loam (deep, poorly drained), Templeton silty loam (deep, moderately drained), Prebbleton silty loam (deep moderately drained),Taitapu silty loam (deep, poorly drained)
Farm I (Block 2)	Flaxton silty loam (deep, poorly drained), Waimakariri loam (moderately deep well drained), Taitapu silty loam (deep, poorly drained)
Farm I (Block 3)	Waimakariri loam (moderately deep, well drained), Rakaia loam (shallow, well drained), Prebbleton silty loam (deep, moderately well drained)
Farm J	Mayfield deep silt loam, Darnley shallow and stony silt loam, Salix deep silt loam on clay loam
Farm K	Templeton silty loam (moderately deep, well drained)
Farm L	Lismore silty loam (shallow, well drained)
Farm M	Longbeach silty loam (moderately drained, poorly drained), Longbeach silty loam over clay
Farm N	Waterton silty loam (shallow, poorly drained), Longbeach silty loam (moderately deep, poorly drained)
Farm O	Longbeach silty loam (moderately drained, poorly drained)
Farm P	Wakanui silty loam (deep, imperfectly drained), Longbeach silty loam (moderately deep, poorly drained), Waimairi peat over silty loam (moderately deep, very poorly drained), Waterton silty loam (shallow, poorly drained), Willowby silty loam (shallow, poorly drained)

3.2. Analysis of Groundwater Nitrogen Concentrations

Groundwater samples were collected monthly from May 2015 to December 2015 to determine NO_3-N concentrations and their possible seasonal variability. Table 5 shows the range, average and when the minimum and maximum NO_3-N concentrations occurred for each farm. Some farmers were able to provide data on previous years NO_3-N concentrations which included Farms C, B, D, F and L. However, where this data could not be provided, an average of the monthly groundwater samples collected was used.

The highest concentration measured was 12.8mg/L (Farm L) and the lowest was <0.05mg/L (Farm G). Very few farms exceeded the NZWDS of 11.3mg/L but the two farms that did exceed this standard did not use the water for drinking purposes.

Farm G is located within close proximity to the Rakaia River and it is likely that river water seepage has a dilution effect on the groundwater used for irrigation, resulting in a significantly lower NO_3-N concentration. Notably, Farm G also predominantly uses surface water to fill a storage pond, and groundwater is only used to top it up when necessary so low NO_3-N concentrations were measured in the pond. Farm K had a similar water source for irrigation, and also had low NO_3-N concentrations that did not exceed 2.0mg/L in the surface and pond water.

Farm A had the deepest well (230 to 240 metres deep) but the NO_3-N concentrations measured here were still significant. Farm B and C were also similar as they ranged in depths between 105 and 130 metres. However, other farms including Farm D (233.5 metres) and Farm G (100metres) were deep and had relatively low NO_3-N concentrations. This suggests that even relatively deep groundwater wells, can have elevated NO_3-N concentrations.

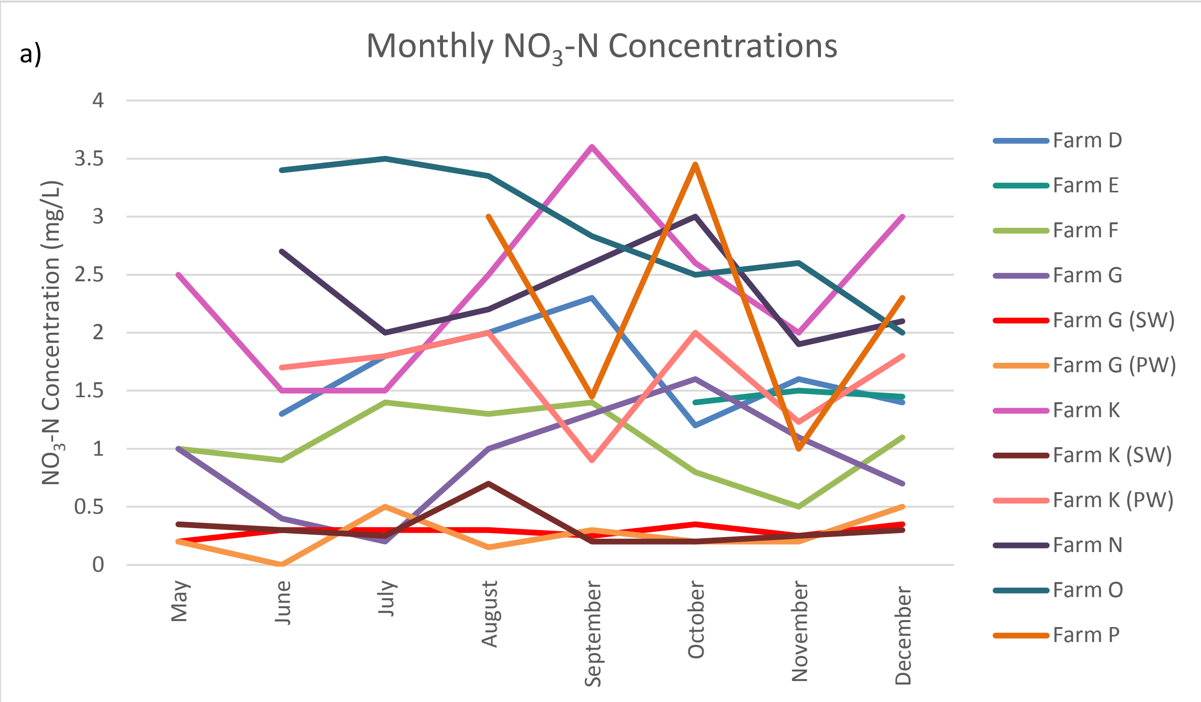
Table 5: NO_3-N concentrations (mg/L) measured in groundwater used for irrigation on farms, unless shaded in grey (SW = Surface Water, PW = Pond Water, NA = Not Applicable).

Farm:	No. of samples	Range (mg/L)	Average (mg/L)	Time Min	Time Max	Well Depth (m)
Farm A	8	2.8 - 6.4	4.3	June	August	230-240
Farm B	8	0.7 - 4.5	2.6	July	August & November	105.83
Farm C	8	1.75 - 5.2	3.8	June	May	125-130
Farm D	7	1.2- 2.3	1.7	October	September	233.5
Farm E	3	1.4 - 1.5	1.4	October	November	90
Farm F	8	0.5 - 1.4	1.1	November	July & September	68
Farm G	6	<0.05 - 1.6	0.9	June	July & December	100
Farm G (SW)	8	0.2 - 0.4	0.3	May	October	**NA**
Farm G (PW)	6	<0.05 - 0.5	0.3	June	December	**NA**
Farm H	8	4.4 - 9.5	6.3	June	October	36-75
Farm I (Block 1)	8	5.5 - 9.6	7.7	May	September	18.2
Farm I (Block 2)	8	5.5 - 11.6	8.5	May	September & October	10.5
Farm I (Block 3)	8	1.9 - 9.9	6.7	May	July	12.5
Farm J	6	2.5 - 5.5	4	August	June	11
Farm K	6	1.5 - 3.6	2.4	June & July	September	80
Farm K (SW)	5	0.2 - 0.7	0.3	September & October	August	**NA**
Farm K (PW)	7	0.9 - 2.0	1.6	September	August	**NA**
Farm L	7	4.2 - 12.8	7	May	July	70
Farm M	7	1.7 - 4.8	3.6	September	July	60.96
Farm N	7	2 - 2.7	2.4	June	May	50
Farm O	7	2.0 - 3.5	2.9	November	June	45-60
Farm P	5	1.0 - 3.5	2.2	October	August	84

Seasonal Variation

Hanson (2002) and Hayward & Hanson (2004) identified that NO_3-N concentrations typically peak during late winter to early spring (July to August). However, out of the 22 water sources (groundwater, surface water and pond water) on the farms sampled, only ten showed peaks in July and August while the rest experienced other varied trends (see Figure 30). Out of the ten farms that experienced these peaks, seven of them also peaked in NO_3-N concentrations at various other times throughout the sampling period. From the NO_3-N concentrations measured on all farms, it was clear that none of them had similar trends to each other.

As Figure 30 shows, Farms I and L had substantial peaks in the NO_3-N concentrations measured. It is likely that Farm I experienced higher NO_3-N concentrations as the irrigation water is sourced from shallow wells (10.5 to 18.2 metres). Farm L is also situated downstream from a meat processing company, which potentially could cause higher NO_3-N concentrations.



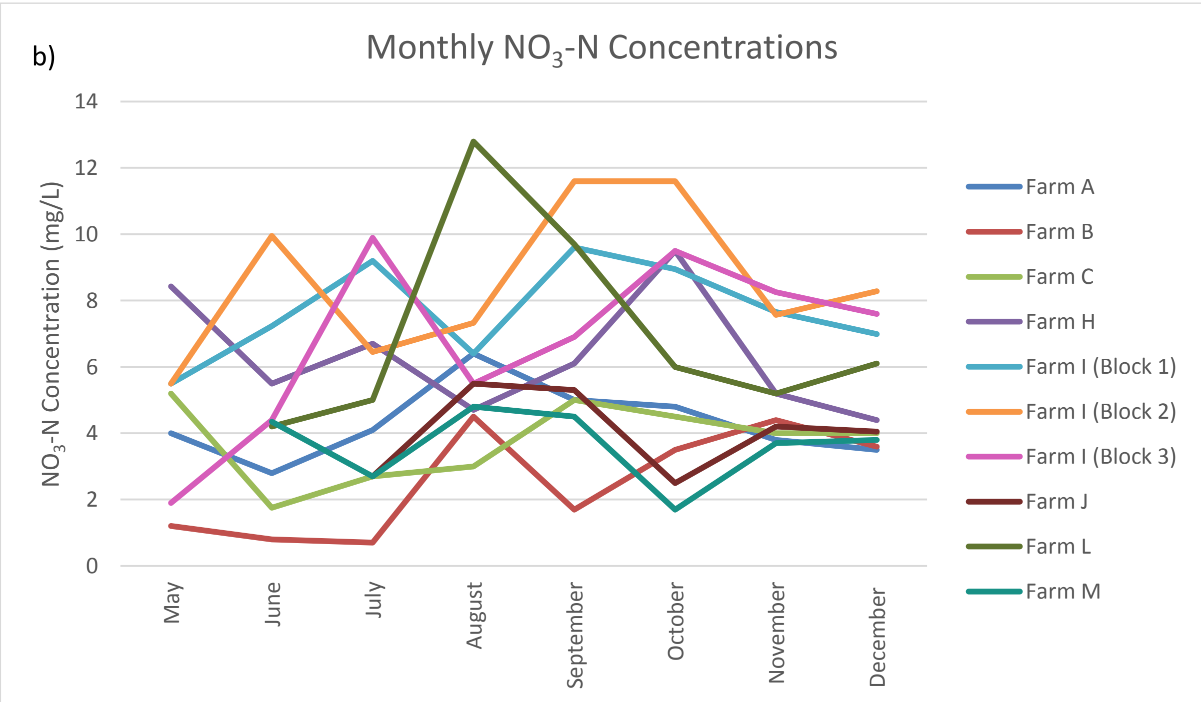


Figure 30 (a) and (b): Monthly NO_3-N Concentrations (mg/L) in groundwater for irrigation.

3.3. Other Water Parameters in Groundwater

Temperature, dissolved oxygen, conductivity and pH were also measured when groundwater samples were taken. Correlations between NO_3-N and these parameters are shown on Table 6. R^2 values from a linear regression were used to determine how strong the correlation was. Any R^2 values > 0.7 were considered to be strong and indicate a correlation between NO_3-N concentrations and the water parameter.

From the 22 water sources measured, 5 of them had one or more parameters that had a correlation with NO_3-N concentrations measured on farm. The other 17 farms had no correlation with the four water parameters. NO_3-N concentrations measured on Farm K had a strong correlation with temperature. NO_3-N concentrations were strongly correlated with dissolved oxygen and conductivity on Farm B. NO_3-N concentrations on Farm E had a correlation with conductivity. NO_3-N concentrations measured on Farm G had a strong correlation with temperature and pH. Dissolved oxygen had a significant correlation with the NO_3-N concentrations on Farm L. The results shown in Table 6 suggest there was no strong relationship between water parameters measured and NO_3-N concentrations for majority of the farms.

Table 6: R^2 Values showing the correlation of NO_3 –N concentrations with dissolved oxygen, conductivity, temperature and pH (Correlations <0.7 shown in bold).

Farm:	No. of Measurements	Dissolved Oxygen	Conductivity	Temperature	pH
Farm A	8	0.04	0.4	0.02	0.07
Farm B	8	**0.7**	**0.7**	0.03	0.5
Farm C	8	0.4	0.02	0.4	0.1
Farm D	7	0.3	0.4	0.09	0.004
Farm E	3	0.008	**0.9**	0.3	0.4
Farm F	8	0.5	0.002	0.2	0.09
Farm G	6	0.1	0.3	**0.9**	**0.8**
Farm G (SW)	8	0.3	0.2	0.3	0.1
Farm G (PW)	6	0.06	0.03	0.02	0.03
Farm H	8	0.07	0.07	0.02	0.1
Farm I (Block 1)	8	0.05	0.1	0.01	0.3
Farm I (Block 2)	8	0.2	0.02	0.07	0.2
Farm I (Block 3)	8	0.4	0.06	0.01	0.02
Farm J	6	0.03	0.03	0.3	0.1
Farm K	6	0.3	0.4	**0.8**	0.6
Farm K (SW)	5	0.008	**0.9**	0.05	0.07
Farm K (PW)	7	0.07	0.2	0.4	0.3
Farm L	7	**0.8**	0.1	0.5	0.1
Farm M	7	0.2	0.09	0.02	0.09
Farm N	7	0.008	0.3	0.4	0.04
Farm O	7	0.03	0.02	0.008	0.4
Farm P	5	0.002	0.04	0.07	0.5

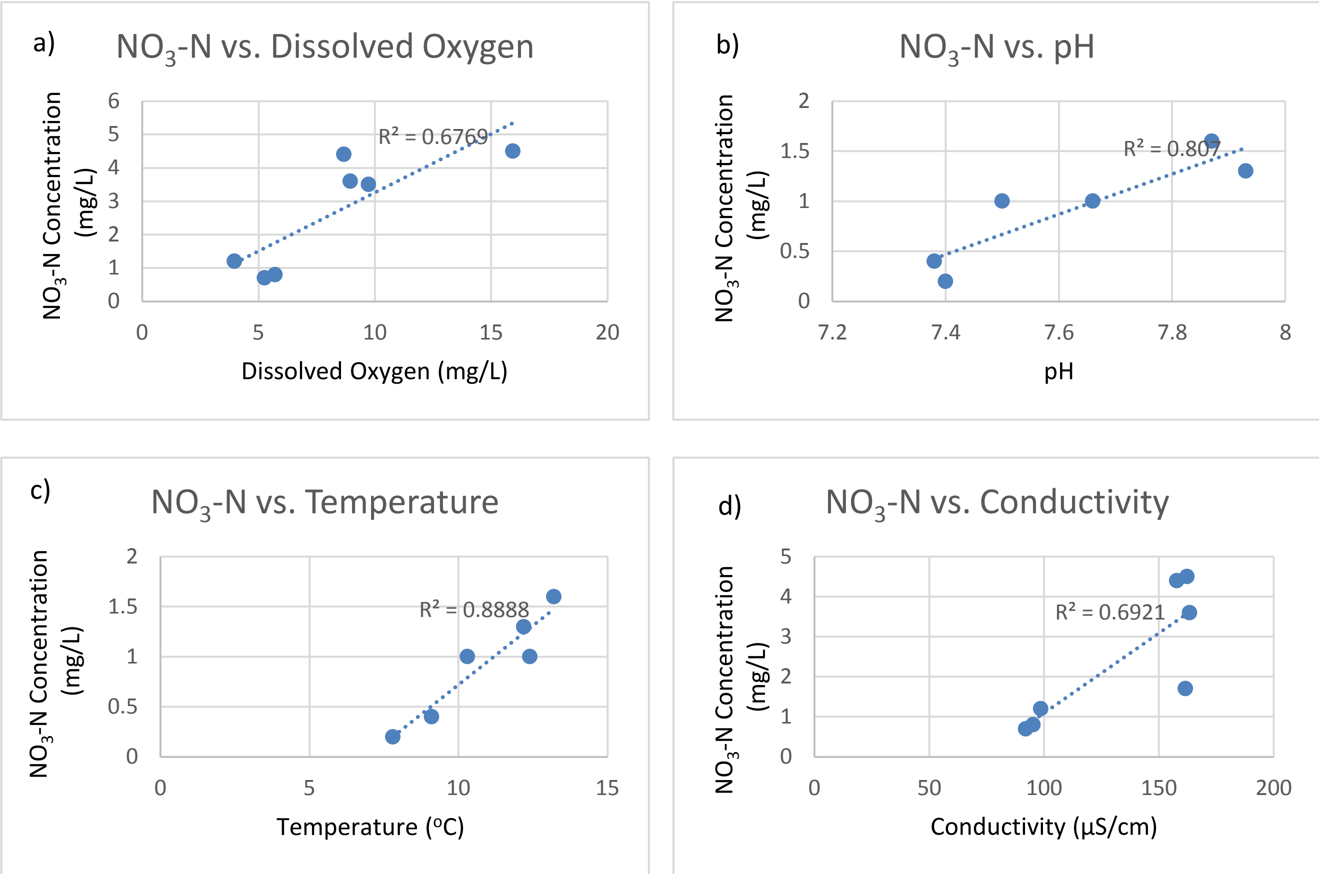


Figure 31: Example of strong correlations between a) Dissolved Oxygen (Farm B), b) pH (Farm G), c) Temperature (Farm G), d) Conductivity (Farm B) and NO_3-N Concentrations.

3.4. Nutrient Load Calculations

The 2014/2015 season data from farmers were used to calculate nutrient loads for each of the farms. Since Farms G and K used both surface water and groundwater for irrigation, the NO_3-N concentration measured from the pond water was used in the nutrient load calculation as it was determined this would be a fair representation for nitrogen contributed to the land from irrigation. Figure 32(a) shows a comparison between the amount of nitrogen fertiliser applied for each farm and the NO_3-N contribution from groundwater irrigation as determined by the nutrient load calculation. There were significant variations in the amount of NO_3-N contributed from irrigation for each farm (see Figure 32(a)). The higher the NO_3-N concentration and irrigation application rate, the greater the NO_3-N contribution was. Farms A, C, I (all blocks), J and L all had NO_3-N concentrations greater than 5 mg/L. Therefore, the amount of NO_3-N contributed to the farm was also high. Farms E, F, and Farm G all had NO_3-N concentrations less than 2.0 mg/L so contribution to land was significantly less.

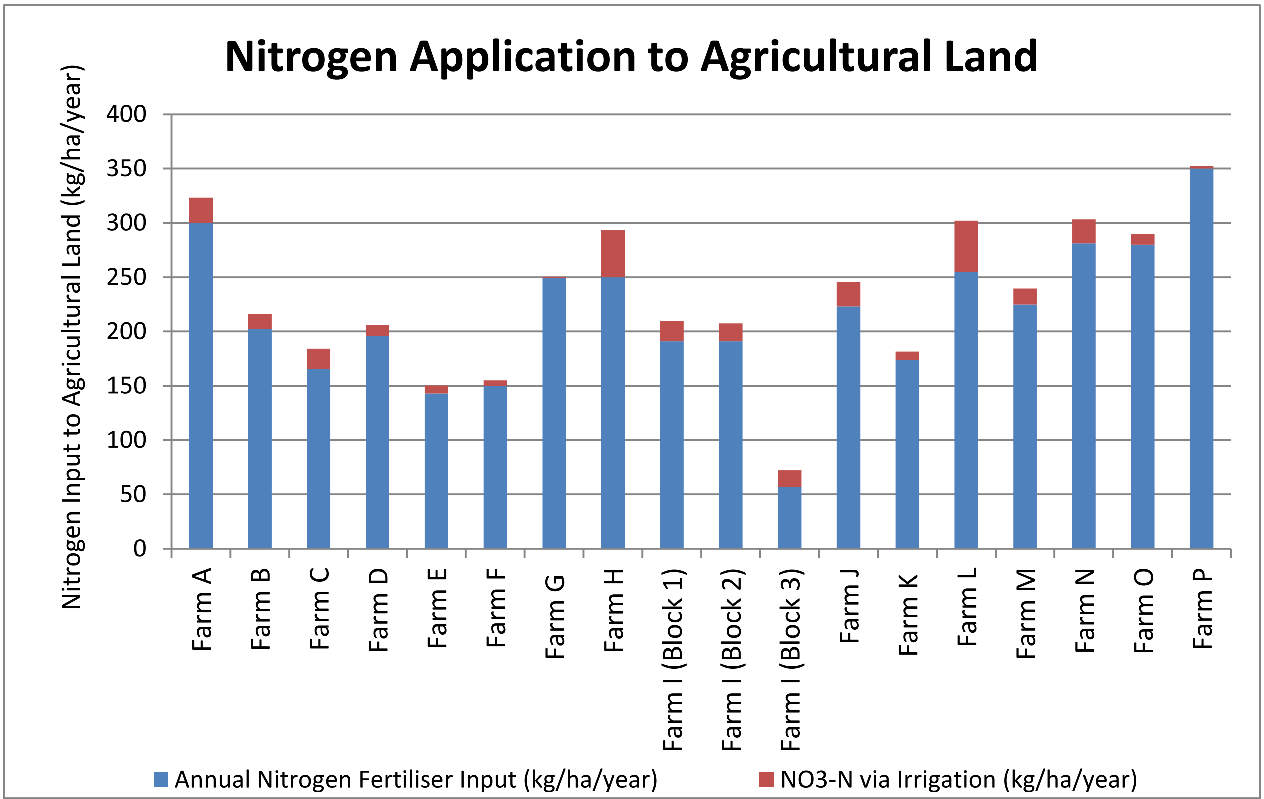


Figure 32(a): Comparison between nitrogen from fertiliser application (2014/2015 season) and NO_3-N contributed via irrigation to each farm over same period.

In a second comparison between the amount of nitrogen fertiliser applied to the land and the amount of NO_3-N contributed from irrigation, the figures were converted into a percentage (see Figure 32(b)). The largest NO_3-N contribution was Farm I (Block 3) (21%). This farm had an average NO_3-N concentration of 6.3mg/L. While Farm G had the lowest contribution (0.5%) due to the low NO_3-N concentrations measured. The average NO_3-N contribution from irrigation for all farms was 9% with six of the farms having a contribution greater than 10%. Again, these contributions from irrigation were highly dependent on the NO_3-N concentrations measured at each farm. Depending on the nitrogen amount coming from groundwater determined how much nitrogen fertiliser application could be reduced. Figure 32(b) shows further evidence that when NO_3-N concentrations are higher in the groundwater the more significant the contribution was to the farm.

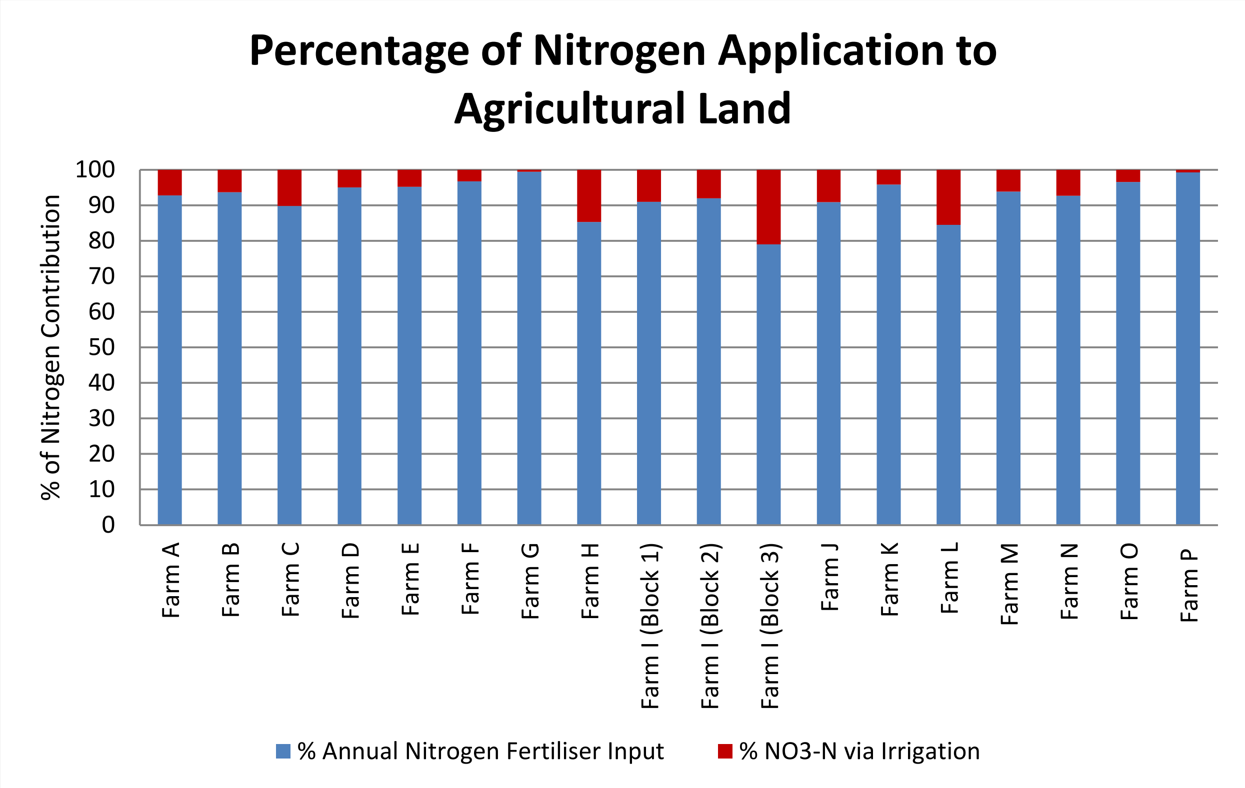


Figure 32(b): Comparison between N fertilisers applied to farms and NO_3-N contributed via irrigation during the same period on Figure 32(a).

3.5. OVERSEER® Nutrient Budget Scenarios

Using the information collected from farmers and the OVERSEER® files provided by Ravensdown, Ballance and Fonterra, three different scenarios were produced. Scenario 1 used the OVERSEER® nitrogen default value (2.5 mg/L) for irrigation contribution. Scenario 2 involved using the actual NO_3-N concentrations that were measured for each farm to replace the OVERSEER® nitrogen default value. Scenario 3 also involved using the actual NO_3-N concentration measured as well as a reduction in nitrogen fertiliser application based on each farms nutrient load. These scenarios were then compared with each other to determine how or if there were any changes in nitrogen losses.

3.5.1. Comparison of OVERSEER® Output Variables between Scenarios

OVERSEER® produces various reports which outline how nutrients are being moved around a farm. This includes calculating the amount of nutrients being added or removed by changing the NO_3-N concentrations contributed by irrigation water and/or reducing fertiliser application.

Nitrogen Losses from Farms

The main losses for nitrogen (losses to water and losses to atmosphere) are shown for each scenario on Figure 33 and 34. The changes in nitrogen losses for all three scenarios were not as significant as expected as there were no differences between scenarios for some farms.

The most relevant variable to this research is the amount of nitrogen lost to water as this is essentially what is returned back to the water environment and could cause environment degradation or be used again in the future. When the NO_3-N concentration was changed in Scenario 2 and 3 to the actual measured NO_3-N in groundwater, the amount of nitrogen lost to water increased or decreased. Farms A, C, H and L all increased in nitrogen losses in Scenario 2 as they all had NO_3-N concentrations greater than the default value. However, these farms also decreased in nitrogen losses for Scenario 3 for the same reason and since the contribution of nitrogen from groundwater were enough to reduce fertiliser application (up to 21%). Farms D and J also experienced a reduction in nitrogen losses for Scenario 3 but saw no change in Scenario 2. Farms F, G and K all saw a decrease in their nitrogen losses for Scenario 2 and 3. Farms N and O had no change between scenarios which is likely as their actual measured NO_3-N concentrations did not vary significantly in comparison to the OVERSEER® nitrogen default value (2.5 mg/L).

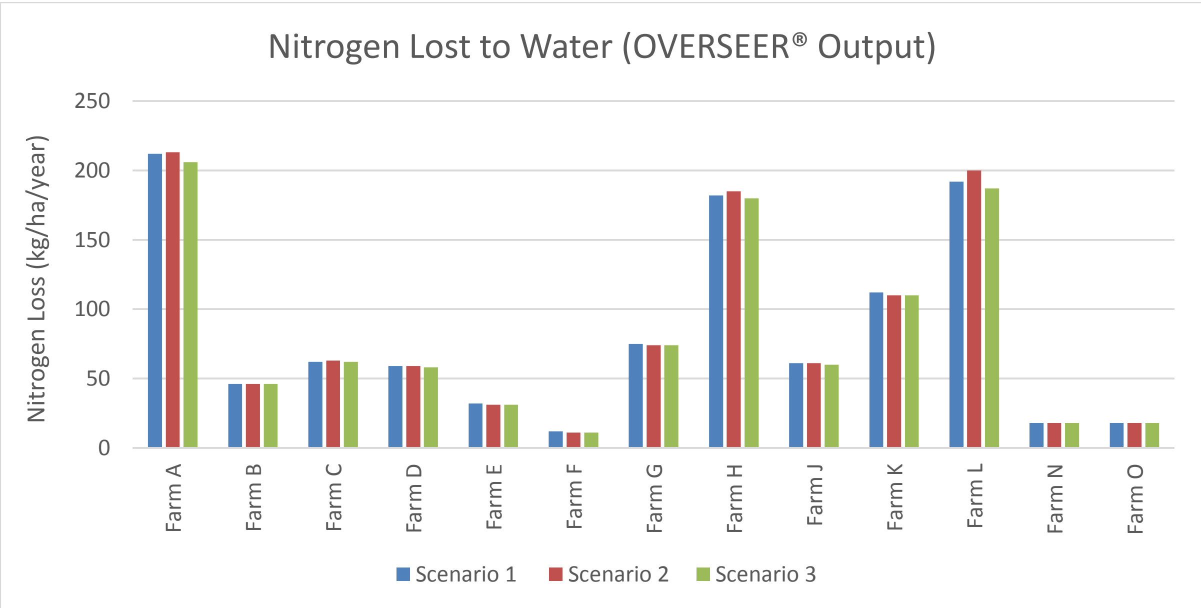


Figure 33: Nitrogen lost to water as calculated by OVERSEER® for all three scenarios.

There were also some variations in the nitrogen losses to atmosphere between the three scenarios (See Figure 34). Farm L was the only farm that experienced an increase in nitrogen losses for Scenario 2. Farms A, B, H, J, L and N all had decreases in nitrogen losses for Scenario 3. While Farm F was the only farm that experienced a decrease in nitrogen losses for both Scenario 2 and 3. Farm H had the largest reduction between Scenario 1 and Scenario 3 as the nitrogen lost went from 185 kg/ha/year to 166 kg/ha/year. There was no change in nitrogen losses to the atmosphere for Farms B, C, D, E, G, K and O between the three scenarios.

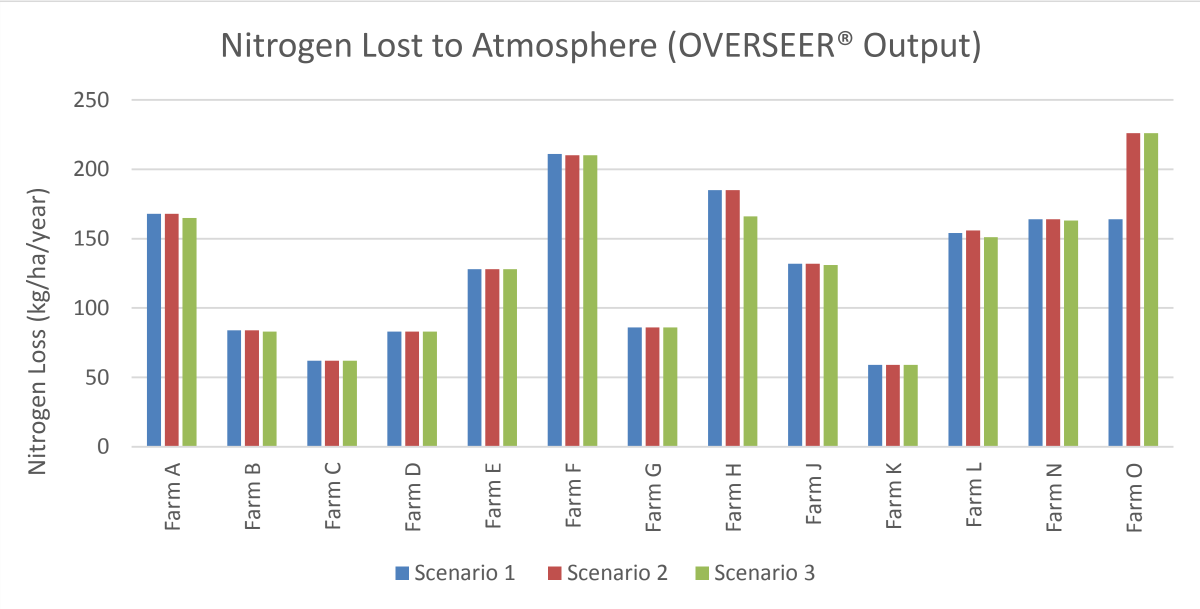


Figure 34: Nitrogen lost to atmosphere as calculated by OVERSEER® for all three scenarios.

Nitrogen Added by Irrigation

OVERSEER® has the ability to calculate the amount of nitrogen that is being added by irrigation, based on NO_3-N concentrations in irrigation water that are used in the model. The accuracy of this is uncertain as OVERSEER® does not directly ask the user to input the annual irrigation volume used for the particular farm. However, Figure 35 shows the outputs as calculated by OVERSEER®, to show how changing the nitrogen concentrations in irrigation water can change the outputs assumed by OVERSEER®. This will be useful information when it comes to deciding if this is an aspect that farmers need to be considering as part of their OVERSEER® nutrient budgets for regulatory management (i.e. nutrient limits and OVERSEER® Nitrogen Baselines).

As shown on Figure 35, there are some significant variations between the three scenarios for each farm. Again, this is strongly influenced by the actual NO_3-N concentrations that were measured in groundwater for each farm. The NO_3-N concentrations measured at Farms F and G were significantly lower than the OVERSEER® default of 2.5mg/L, resulting in a lower amount of nitrogen added via irrigation. While for farms with higher NO_3-N concentrations (including Farms A, H, L and O), the amount of nitrogen added to the farm from irrigation increased above the default.

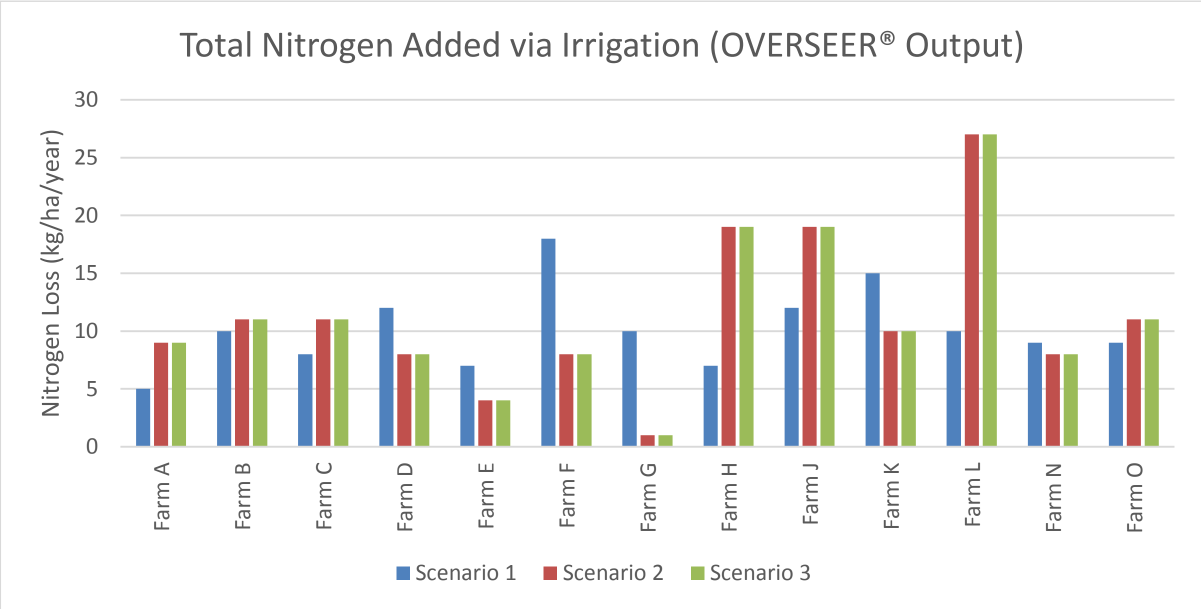


Figure 35: Nitrogen added to each farm via irrigation based on OVERSEER® calculation.

Total Nitrogen Surplus on Farms

OVERSEER® calculates the amount of nitrogen that is in surplus for any particular farm. This variable could be significant to farmers as it indicates how much nitrogen could be reduced without decreasing production rates (i.e. pasture/crop growth, supplementary feed production). OVERSEER® sets a benchmark figure indicating what farmers should aim for, for their nitrogen surplus, which is 123 to 191 kg/ha/year. This benchmark is calculated based on a typical New Zealand farm, so some farms vary significantly from this figure.

Figure 36 shows the comparison between the three scenarios and how the nitrogen surplus for each farm changed. Out of the 13 farms, Farm F was the only farm that was within the benchmark for all three scenarios. Scenario 3 also caused five of the farms to decrease in nitrogen surplus as fertiliser application was reduced. These decreases in nitrogen surplus occurred for farms that had either a low NO_3-N concentration or high reductions in nitrogen fertiliser application based on their nutrient loads. However, for Scenario 2 the majority of the farms had an increased nitrogen surplus for and in particular farms that had relatively high NO_3-N concentrations in groundwater (Farm H and L).

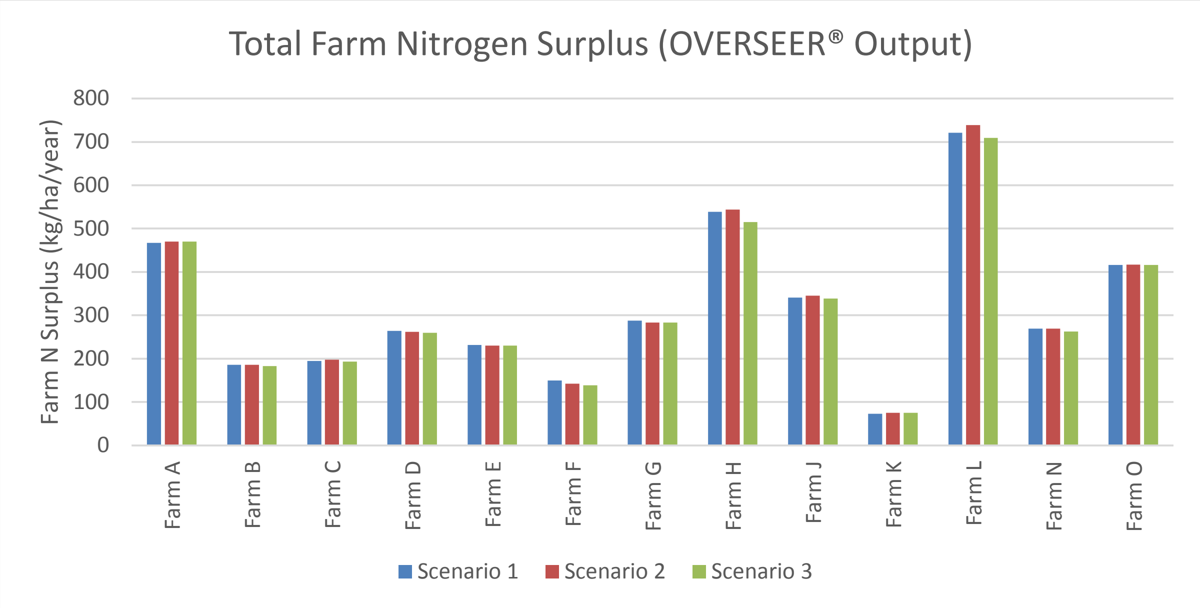


Figure 36: Comparison between scenarios on the amount of nitrogen surplus on each farm as calculated by OVERSEER®.

Nitrogen Conversion Efficiency

OVERSEER® has the ability to calculate the efficiency of nitrogen conversion on any particular farm which is given as a percentage. The nitrogen conversion efficiency is a measurement of the amount of nitrogen in inputs that is converted to products that are taken off farm or put into storage. OVERSEER® has given a benchmark range for what a likely nitrogen conversion efficiency rate should look like and this is between 27 and 35%. Again, this is based on a typical New Zealand farm, so percentages may change depending on farm type.

Figure 37 shows how the nitrogen conversion efficiency changed between the three scenarios. Farms A, C, D, E, G, J and O all experienced no change in conversion efficiency rates for all three scenarios. Farms F and N had an increase in percentage for Scenario 2 and 3. However, Farms B, H, K and L decreased in nitrogen conversion efficiency for Scenario 2 and/or 3. Farms E, G and J were all between the benchmark (27 – 35%) for all three scenarios. Farm Ns nitrogen conversion efficiency percentage came into the benchmark for

Scenario 3 but the percentage for Farm F changed in Scenario 2 and 3, removing it from the benchmark range.

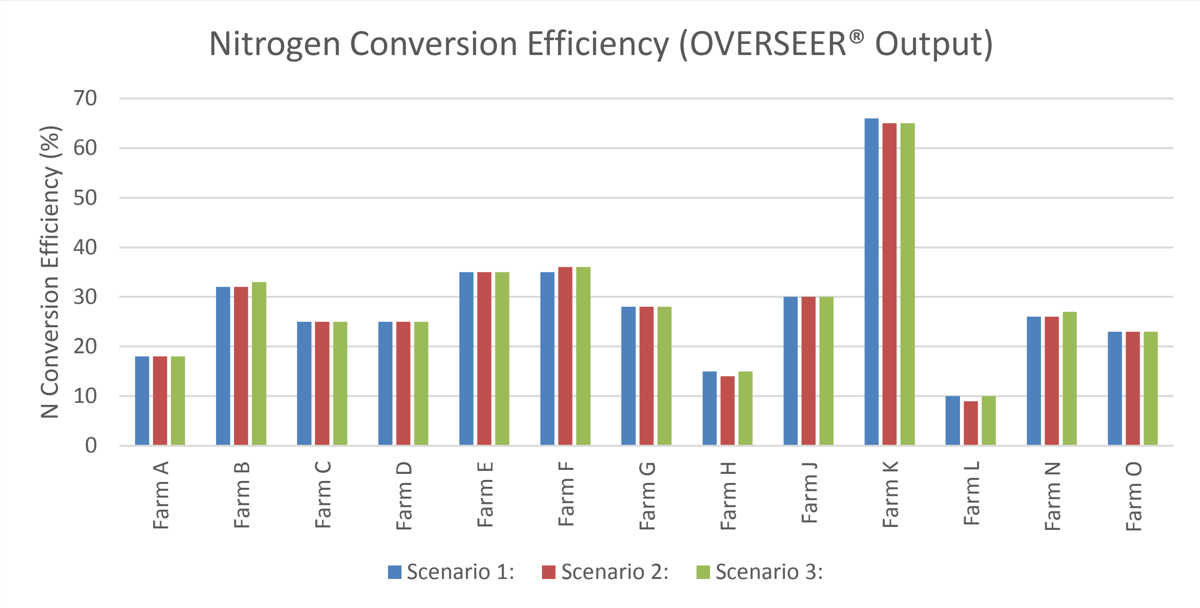


Figure 37: Comparison in nitrogen conversion efficiency rates for all three scenarios as calculated by OVERSEER®.

3.6. Cost Benefit Analysis for Changes in Fertiliser Costs

One of the key aspects of this research was to analyse how the data collected is going to benefit farmers and their nutrient management. Based on fertiliser costs that are put into OVERSEER®, the model is able to calculate the total cost of fertiliser per hectare, depending on the type and amount of fertiliser applied.

Figure 38 shows how the cost of fertiliser changed for each of the scenarios that were used in OVERSEER®. It was expected that there would be no changes between Scenario 1 and 2 as the amount of fertiliser applied to the farm did not change. However, for Scenario 3 there were some significant reductions in fertiliser costs. Farms A, B, C, D, F, H, J, K, L, N and O had reductions in their fertiliser costs, as they had some contribution from nitrogen in groundwater. Farms H and L had the highest reduction in fertiliser cost with Farm H saving $46.32 per hectare while Farm L had a total savings of $44.34 per hectare. Farms L and H had the largest contribution of nitrogen so would have the largest reduction in fertiliser costs. In contrast, Farms E and G fertiliser costs did not change between the three scenarios due to a lower contribution of nitrogen from groundwater.

The reliability of these variations in fertiliser cost is questioned as OVERSEER® is unable to calculate the cost of just nitrogen fertilisers. Figure 38 shows how the costs will be reduced based on all the fertiliser applied to the farm instead of just nitrogen fertilisers. However, these results are only used to show that there is some reduction between the three scenarios in fertiliser cost based on each farms nitrogen contribution from groundwater.

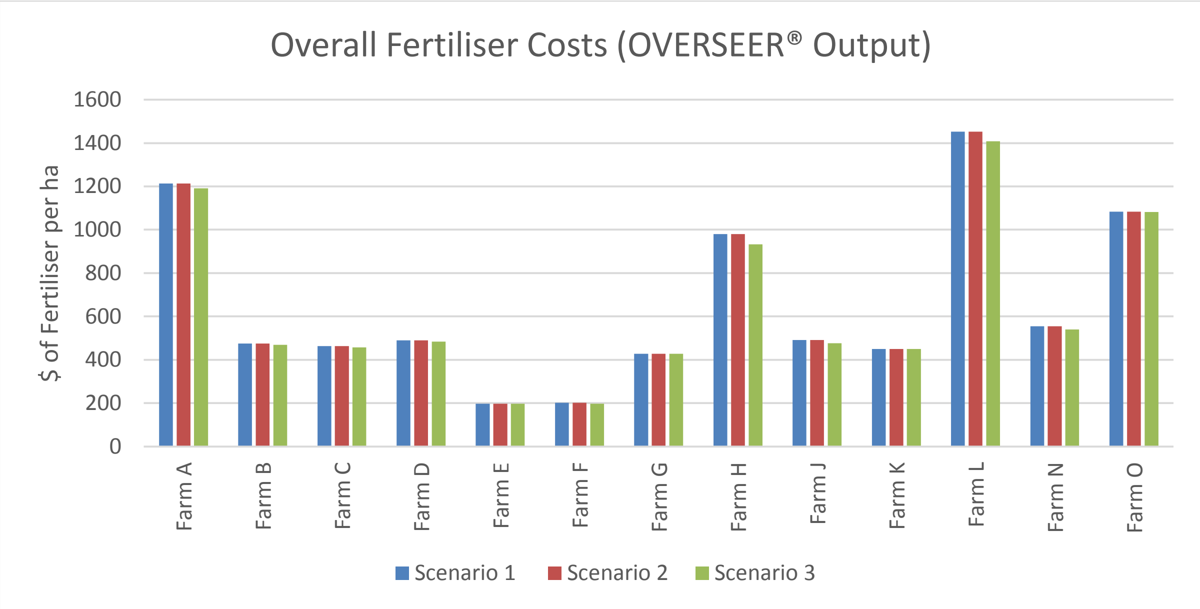


Figure 38: Comparison in fertiliser costs between each scenario as calculated by OVERSEER®.

3.6.1. Reduction in Cost of Nitrogen

Table 7 shows the reduction in the cost of nitrogen per kilogram for all 16 farms that were researched. The price of nitrogen fertiliser applied was based on the OVERSEER® default of $1.48 per kilogram. Urea was the common nitrogen fertiliser used by farmers and it contains 46 percent of nitrogen which is considered in the price per kilogram of nitrogen in OVERSEER®. It is likely that this cost could change depending on the fertiliser company farmers' use. The results from the nutrient loads were used to determine how much the cost of nitrogen fertilisers would be reduced by if they used nitrogen from the groundwater. This calculation provides more accurate results for reductions in nitrogen fertiliser costs compared to OVERSEER® results discussed above as the model only calculates the cost for all types of fertilisers applied to the farm.

The reductions in costs were strongly influenced by the amount of nitrogen that was coming from the groundwater. There was a large range in the reductions of cost which varied between \$286.70 and \$40,304.80 in total, with an average of \$6,606.20 per year for all 16 farms. Farms G and P are two farms that do not have high NO_3-N concentrations so the reductions in cost are not as significant as other farms. However, Farms H, L and N had significant reductions in cost as these are quite large farms in size.

Table 7: Reduction in the cost of nitrogen per kilogram for all 16 farms.

Farm	Reductions in the Cost of Nitrogen (\$/year)
Farm A	\$4,630.60
Farm B	\$3,467.60
Farm C	\$4,036.10
Farm D	\$3,939.60
Farm E	\$1,697.10
Farm F	\$1,472.00
Farm G	\$286.70
Farm H	\$13,685.00
Farm I	\$2,155.70
Farm J	\$5,666.60
Farm K	\$4,833.20
Farm L	\$40,304.80
Farm M	\$4,560.30
Farm N	\$9,976.50
Farm O	\$3,389.20
Farm P	\$495.30

4. Discussion

4.1. Assessment of Farm Data

Overall, data provided by the farmers was reliable and allowed for a thorough comparison between different farm types throughout Canterbury. Taking monthly groundwater samples proved to be useful in determining possible variables that caused varying NO_3-N concentrations and showed that seasonal trends do not necessarily have an impact on these concentrations. However, correlations between the other water parameters measured (i.e. dissolved oxygen, conductivity, temperature and pH) and NO_3-N concentrations were not strong. This indicated that the water parameters did not influence the variable NO_3-N concentrations measured in the groundwater samples.

It is important to consider that the nitrogen contribution from irrigation water on the farms is likely to annually change depending on the climatic conditions experienced, changing the nutrient load calculated. While 21 percent was the largest contribution calculated for the 2014/2015 season, other irrigation seasons experienced contributions of up to 49.9 percent which could reduce half of the nitrogen fertiliser applied within that year. A 9 percent average in nitrogen contribution between the 16 farms suggests that there is an adequate amount of NO_3-N coming from the groundwater, allowing for reductions in nitrogen fertiliser applications.

Due to the varying climatic conditions that are experienced in Canterbury, it was necessary to collect five years of data from farmers to allow for this variability. A drier irrigation season will see farmers using more water (depending on water restrictions) and in a wetter season less water will be consumed on farms. Since 2014/2015 was the driest irrigation season out of the last five years, the water consumption was relatively high compared to previous years.

When the application of groundwater to the farm is high, this will also cause a higher nitrogen contribution applied. Nitrogen contributions from groundwater are farm specific and this is an aspect that farmers need to consider when using nitrogen in groundwater as an alternative to nitrogen fertilisers. When less water is used for irrigation, more fertiliser will be needed to ensure optimum growth of crops and/or pastures.

4.2. Variables Influencing Nitrogen Concentrations on Canterbury Farms

The trends in NO_3-N concentrations varied significantly between all 16 farms and there we no distinct trends within the water samples analysed. This made it difficult to determine which variables influence the NO_3-N concentrations on each farm. Therefore, several possible variables that can cause changes in the concentrations are discussed below.

4.2.1. Groundwater Well Depth

NO_3-N concentrations indicated that the depth at which groundwater was being drawn from did not influence the concentrations measured on the farm. Although it is expected that shallower wells (typically no greater than 50 metres deep) are more susceptible to land use changes and should have higher NO_3-N concentration compared to deeper, more diluted wells. This was apparent on Farms H, J and I as these farms all had shallow wells with high NO_3-N concentrations. However, Farm L had a well depth of 70 metres and the NO_3-N concentrations measured were obviously still influenced by land use occurring above the farm. As discussed above, this farm is located downstream of a meat processing plant in Ashburton, where the NO_3-N concentrations are influenced by the discharges from this. Therefore, this suggests that land use changes could potentially be influencing deeper groundwaters as well as shallow groundwater.

4.2.2. Land Use Changes

Nolan & Hitt (2003) found that NO_3-N concentrations greater than 3.5mg/L are caused by land use changes in the United States. If this is the situation in Canterbury, then the majority of the NO_3-N concentrations measured on the farms are influenced by various land uses that occur in the region. The changes in land uses that could cause NO_3-N concentrations higher than 3.5mg/L could include the increase in nitrogen fertiliser use that occurred 30 years ago and the conversion of dryland farms to irrigated dairy farms in the last 20 years in Canterbury.

4.2.3. Canterbury Groundwater Aquifer Systems

Rapid increases in the groundwater abstraction for irrigation have had a significant impact on the aquifers and the NO_3-N concentrations in Canterbury, particularly in the Ashburton District. Close, Morgenstern & van der Raaji (2011) identified that the use of older groundwater for irrigation can affect the geochemistry of the water that is recharged back into the aquifer. Accordingly, altering groundwater flow patterns and affecting the NO_3-N concentrations measured in the Ashburton District (Close, Morgenstern & van der Raaji, 2011).

The groundwater aquifers located within the Canterbury Plains act as a single aquifer rather than multiple different ones (Hanson & Abraham, 2013). In both the Selwyn and Ashburton Districts, the groundwater flows directly down the plains and ends up at the coast (Hanson & Abraham, 2013). The only difference between the two districts is that the surface water and groundwater in the Selwyn District are highly interconnected. Groundwater that is sourced from the recharge of alpine rivers (Rakaia and Waimakariri Rivers) in the upper catchment, flows through to the deeper parts of the aquifer system and then appears again at the coast. Whilst the shallower groundwaters are recharged from land surfaces and is discharged into lowland streams of the Selwyn District via springs (Hanson & Abraham, 2013).

In the lower catchment of the Ashburton District and in particular between the Ashburton and Rangitata Rivers where some of the participating farms were located, the groundwater system differs to the Selwyn catchment. Instead of the groundwater rising through springs into lowland streams, the flow is downward towards the coast carrying nitrate from the surface into deep parts of the aquifer system (Hanson & Abraham, 2013). Therefore, effects from land use are likely to percolate from the surface into the deeper aquifers which could explain the NO_3-N concentration measured on Farm L. Groundwater is generally recharged by rainfall (three quarters) or irrigation water (one quarter) from the surface (Hanson & Abraham, 2013). The groundwater in the Ashburton area is less influenced by river recharge compared to the Selwyn District (Scott, 2004). Therefore, higher NO_3-N concentrations are observed at depths over 100 metres and this was detected in the concentrations measured on some of the farms in the Ashburton District (including Farms L and M).

The groundwater in the Selwyn District is also primarily recharged from alpine rivers as well as soil drainage from land (Hanson & Abraham, 2009). Thus, a significant amount of the NO_3-N in the deeper groundwater is diluted from the river water. Since the NO_3-N concentrations in the alpine rivers are relatively low, this causes the concentrations measured in the groundwater to also be low. This was apparent on Farms D, E, F, and G as the NO_3-N concentrations measured were less than 2.0 mg/L. Farm K in the Ashburton

District is also likely to be influenced by river water as half of the irrigation source is from the Rakaia River, causing lower NO_3-N concentrations.

4.2.4. Seasonal Variations

From the results shown on Table 5 and Figure 32(a) and (b), seasonal changes did not cause trends in the NO_3-N concentrations measured on all the farms. Each farm experienced the measured maximum and minimum NO_3-N concentrations at varying times of the year. Most farms had their highest reading in July, August, September and October, while majority of the lowest readings were in May, June, July and September, showing no significant seasonal trends.

As discussed above, Hanson (2002) and Hayward & Hanson (2004) have identified that higher NO_3-N concentrations are detected during late winter (July) through to early spring (August). This commonly occurs when leaching is high, as the soils are significantly wetter, allowing for nutrients (such as nitrate) to percolate through the soil into the groundwater. Although this was apparent for 10 of the water sources measured, the other 12 had their highest reading either in May, June, September, October or November. This is the opposite of what Hanson (2002) and Hayward & Hanson (2004) found from their annual monitoring for ECan. Therefore, the NO_3-N results found in this research suggest that there are other factors causing NO_3-N concentrations to peak at different times of the year.

4.2.5. Leaching Rates

There has been some difficulty in determining leaching rates and how long it takes for the nitrate in the soil to percolate down into groundwater. Lysimeter data has been used to show some indication but this does not show nitrate leaching at extensive depths where groundwater commonly is. As discussed above, there are many causes that influence NO_3-N concentrations but the time it takes for that nitrate to reach the groundwater system is currently unknown and depends on a number of variables (e.g. drainage events, soil type, crop/pasture type, climatic events). It is known that Canterbury has a 20 to 30 year lag effect in the groundwater system and that the NO_3-N concentrations measured now are from land use intensification that occurred during that time. Therefore, the time it takes for nitrate to leach through the soil is a long process and some industries have begun to research leaching in crops.

Pearson and Reynolds (2007) of Crop and Food Research investigated how nitrate leached through a maize grain crop in a sandy soil in the Waikato region. It was discovered that when nitrogen fertiliser was applied in even applications over a typical crop season (i.e. November to May), nitrate movement was measured down to 180 centimetres which is typically the length of maize roots (Pearson & Reynolds, 2007). During this time, the maize crop received water from both rain and irrigation so it was presumed that drainage occurred when the crop's soil moisture content was at full capacity.

Therefore, when determining how this research could be used to determine the varying leaching rates on Canterbury farms, there are some similar and different comparisons. Firstly, the climatic conditions are quite different and in particular the occurrence of rainfall events. The Canterbury region is significantly drier than Waikato, so less rainfall events occur. In 2015, the Canterbury region had minimal drainage events and the annual rainfall for the year was 50 to 70 percent below normal from previous years (NIWA, 2016). Nitrate leaching is dependent on drainage events but if this rarely occurs then leaching rates may decrease. Since maize crops are likely to have the deepest roots at 180 centimetres, it would take a significant drainage event to move nitrate below this depth at a fast rate. This indicates that the nitrate may not be detected in the groundwater aquifers for a considerable amount of years.

Soil type is another variable that influences leaching rates as they all have varying water holding capacities. In research by Pearson & Reynolds (2007), it was assumed that the sandy soil was at field capacity so drainage occurred straight away. For soils that have lower field capacity, leaching rates would be lower as more water will be needed for the soil to reach full capacity before drainage occurs. Leaching rates are similar in silt and clay soils but instead they have a higher field capacity as they have a higher water holding capacity.

The amount of nitrate that is in the soil before leaching occurs, as well as drainage, is a key variable that influence the nitrate concentrations beneath the surface and must be considered.

4.2.6. Variability between Farms

It is likely that the reason for the NO_3-N concentrations measured at each farm is case specific as there is not one distinct trend that has affected all 16 farms concentrations. It could be possible that the factors discussed above interconnect with each other to cause spatial and temporal changes in the NO_3-N concentrations that were measured on the farms.

The argument here is that due to the long lag times that occur in groundwater, it would be impossible to see the nitrate that was leached from the previous season. Hanson (2002) and Hayward and Hanson (2004) have reported that higher NO_3-N concentrations occur in late winter through to early spring as plant growth is less significant. Therefore, suggesting that the nitrate leached in the winter would be observed straight away in the groundwater or in the following season. Although this may be possible in shallow groundwater where NO_3-N concentrations can be greatly influenced by land use changes, it takes a significantly longer time for nitrate to leach into deeper groundwater, as Pearson and Reynold's (2007) research showed. ECan monitors groundwater wells of various depths, which was similar to this research. However, this research suggests that it cannot be assumed that the same trends occur for all groundwater wells throughout the region as not one farm experienced the same trends as others.

For regulation purposes it is extremely important to understand these lag effects in groundwater when considering how nitrate leaches through the water system. Previous work in Southern California found that groundwater lagged 30 to 60 years (Pratt & Adriano, 1973; Pratt, 1984). While, in Nebraska (United States), studies found that the groundwater lagged 20 years (Bentall, 1975). Therefore, when taking into account the groundwater lag effects in Canterbury it is possible that the NO_3-N concentrations measured at farms in the lower catchments could have been also measured at farms in the upper catchments over 30 years ago.

Furthermore, Greismer (2013) looked at estimating lag times in the drainage of irrigation water to groundwater in the Antelope Valley, California (United States). These aquifers were unconfined and it was found that recharge rates were 150 to 250 millimetres per year (Greismer, 2013). This causes complexity when producing regulations and policies as the future of NO_3-N concentrations in groundwater are unknown due to these lag effects. It is quite possible that if the present groundwater quality is an indication of the increase in fertiliser use that occurred over 30 years ago, that the NO_3-N concentrations in the next 30 years could show the effects of stock urine patches from the conversion of dryland to dairy farms. If this is the case, then the groundwater quality is likely to decline further before the results from good management are observed. Therefore, to get a greater understanding of these changes, more frequent monitoring should be undertaken.

4.3. Interpreting Nitrogen Contribution from Groundwater via Irrigation to Agricultural Land

Preliminary research indicated that the amount of nitrogen lost to groundwater would not be sufficient enough to entirely replace nitrogen fertiliser application. Stock urine patches contribute significantly to nitrogen concentrations lost from farms in comparison to other factors including nitrogen fertiliser which needs to be strongly considered. However, any reduction in fertiliser application could have both environmental and economic benefits for both groundwater quality and farmers.

The amount of nitrogen added from irrigation to land was strongly dependent on the average concentration measured on the farm and the amount of irrigation water applied. NO_3-N concentrations for all 16 farms ranged between <0.05 to 12.8mg/L while irrigation volumes ranged between 36,645 and 3,890,422 cubic metres. Farms with a high NO_3-N concentration also had a high nutrient load. Therefore, there was a sufficient amount of nitrogen from groundwater that could be used as a liquid fertiliser to partially reduce fertiliser application to the farm. By reusing the nitrogen present in the groundwater this will potentially turn an issue into a solution as the nutrient is instead recycled back onto the farm.

4.4. Comparison of OVERSEER® Budgets to Nutrient Limits

There are some differences in the nutrient limits between the Selwyn-Waihora and Ashburton Zone according to the LWRP. After 2017, farmers in the Selwyn-Waihora Zone that have a nutrient loss above 15 kg/ha/year or a farm larger than 10 hectares will require both a FEP and resource consent. While in the Ashburton Zone farmers that have a nitrogen loss over 20 kg/ha/year will be required to create a FEP and have resource consent to continue farming.

When comparing these nutrient limits to the nitrogen losses determined in OVERSEER® for all these scenarios for each farm, none of them comply within the limits, as all of the farms had nitrogen losses over both 15 and 20 kg/ha/year. Therefore, using the actual measured NO_3-N concentrations and by reducing the fertiliser application as according to each farm's nutrient load in OVERSEER®, this still did not allow for these nutrient limits to be met.

It is likely that the majority of other farmers in the Selwyn-Waihora and Ashburton Zones will also be above these limits. Most average Canterbury farms including dairy, arable, sheep and beef have more than 10 hectares of land and would have similar nitrogen losses to the farms used in this research. Therefore, majority of these farms will require FEPs and resource consents which could be an aspect that ECan did not carefully consider. Although it is necessary to have nutrient limits so farmers can be aware of their nitrogen losses and to implement more efficient management, these limits still must be achievable.

4.5. Benefits for Farmers

A key objective of this research was to determine how this information could benefit not only the farmers that participated in this research but other farmers in New Zealand that will likely face new water quality and nutrient management regulations.

Each farm that participated in the research received a report which outlined results that were found for that particular farm. These reports included information on the amount of nitrogen contributed from groundwater to land, how much solid nitrogen fertiliser could be reduced by the application of nitrogen filled groundwater and how the farm's OVERSEER® nutrient budget changed due to inputting this information. It is anticipated that this information will help with efficient nutrient management on farm.

4.5.1. Improving Accuracy for OVERSEER® Nutrient Budgets

OVERSEER® has identified that when accurate information is put into the model, a more precise nutrient budget is produced. With the data collected and produced from this research, more accurate nutrient budgets were produced and this is apparent from the results of Scenario 3. By using the actual NO_3-N concentrations that were measured for each farm, the nitrogen variables that OVERSEER® calculates changed accordingly. Where farms had a lower NO_3-N concentration than the OVERSEER® default of 2.5mg/L, the total nitrogen loss decreased, while when the concentration was higher the loss increased.

Having an accurate nutrient budget benefits farmers because by 2017 most farms in Canterbury will have to have calculated their nitrogen baseline as part of nutrient limits set in the LWRP. A nitrogen baseline is an average of nitrogen losses from five years of farming and is calculated by OVERSEER®. The nutrient budgets produced by OVERSEER® are then put into the farm's FEP. This nitrogen baseline will dictate whether farmers are able to develop further on their farms. Therefore, if farmers are not using accurate information in their nutrient budgets then it could work out that they have more or less leeway for future development.

4.5.2. Reduction in Fertiliser Costs

For the farms used in this research, it was determined that there would be a reduction in annual fertiliser costs of up to 21 percent. However, this reduction is dependent on the irrigation application rate and NO_3-N concentrations measured in groundwater. It is also important to consider that 21 percent is typical for a dry season and this may change during wetter irrigation seasons as less water is applied. All farms will be able to reduce their fertiliser costs but it should be determined by the farmer if the reduction will be beneficial and worthwhile to the farm as some reductions may not be as significant as others.

This reduction in costs would be beneficial for any farmer but dairy farmers may appreciate reduction in costs more as the current dairy pay-out is down from what it previously has been and is forecast to have a minimal increase for future seasons. A lower pay-out makes it difficult for farmers to develop further on their farm. Therefore, farmers will be able to make savings on fertiliser costs if nitrogen from groundwater is used as an alternative fertiliser. There are also no additional costs with using nitrogen in the groundwater as the infrastructure necessary is already in place which could be a major incentive for farmers.

4.5.3. Incorporating Nutrient Management into Farm Environment Plans

As part of regulations under ECan's LWRP, farmers will be required to have a FEP which outlines how they are or will manage environmental issues on farm. This document includes how GMPs will be used to reduce any impact to the environment including reducing nitrogen losses from land. Examples of GMPs include fencing off waterways to stock, applying fertiliser at appropriate times and using irrigation infrastructure that applies water efficiently.

Using nitrogen from groundwater as an alternative to solid fertiliser could be implemented as a form of GMP in these FEPs. By using the high NO_3-N concentrations as fertiliser it will essentially recycle the nutrients iand reduce the nitrogen present in the groundwater. It is anticipated that there would be a reduction in the nitrate in the groundwater as the concentrations would become more diluted due to recycling of these nutrients. Further monitoring and analysis would be required to determine how the NO_3-N concentrations could possibly change by using nitrogen in groundwater.

However, since the amount of nitrogen that is added to land from groundwater is dependent on the NO_3-N concentration, a decision tree has been produced to determine if farmers should include this GMP in their FEP (See Figure 38). This decision tree was created based on the contribution of nitrogen from groundwater for all 16 farms that were used in this research. From these results it was determined that farms over 50 hectares may have a significant contribution of nitrogen from groundwater. Farms that are smaller than this and have a nutrient load less than 10 percent will not be required to include this in their FEP.

This research concluded that the size of irrigated land is also a key variable for nitrogen contribution. Even though the farms used in this research were relatively large (over 100 hectares), farms that are between 50 and 100 hectares can still have significant contribution as the nitrogen is being applied to a smaller area. Although the NO_3-N concentration may not greater than 3.5mg/L, due to the smaller size of the area water is applied to, this will still make the contribution relevant.

As Nolan and Hitt (2003) specified, NO_3-N concentrations greater than 3.5mg/L were likely caused by land use changes (in the United States), any farms that had a concentration over this would need to take the nitrogen contribution into consideration for FEPs. It is also important to consider how irrigation application rate can influence contribution depending on the climatic trends within the season. This decision tree suggests that farms that have an irrigation rate over 500,000 cubic metres will also have a significant contribution which should be included in the farm's FEP. However, it should be considered that this threshold could be subject to change depending on other NO_3-N concentrations, irrigation application rates and varying farms sizes that occur around the region and country.

The farmers that may have to include this GMP in their FEP will be required to annually monitor the NO_3-N concentrations in groundwater and be aware of changing water application rates to ensure their nitrogen contribution is still significant throughout different irrigation seasons. The data has already suggested that the amount of total nitrogen added to land from groundwater can change annually depending on the NO_3-N concentration and the irrigation application rate for that season (see Appendix 4).

FEPs obtain management objectives and required outcomes that include irrigation and nutrient management. Irrigation management requires farmers to optimise water use on their farms and this research can assist with this as the nitrogen is recycled for beneficial uses. Nutrient management is also achieved by this GMP as the main objective in FEPs is to reduce any losses from the farm to waterways. By using the nitrogen in the groundwater, losses are reduced as fertiliser application rates are decreased which is contributes to the losses from a farm.

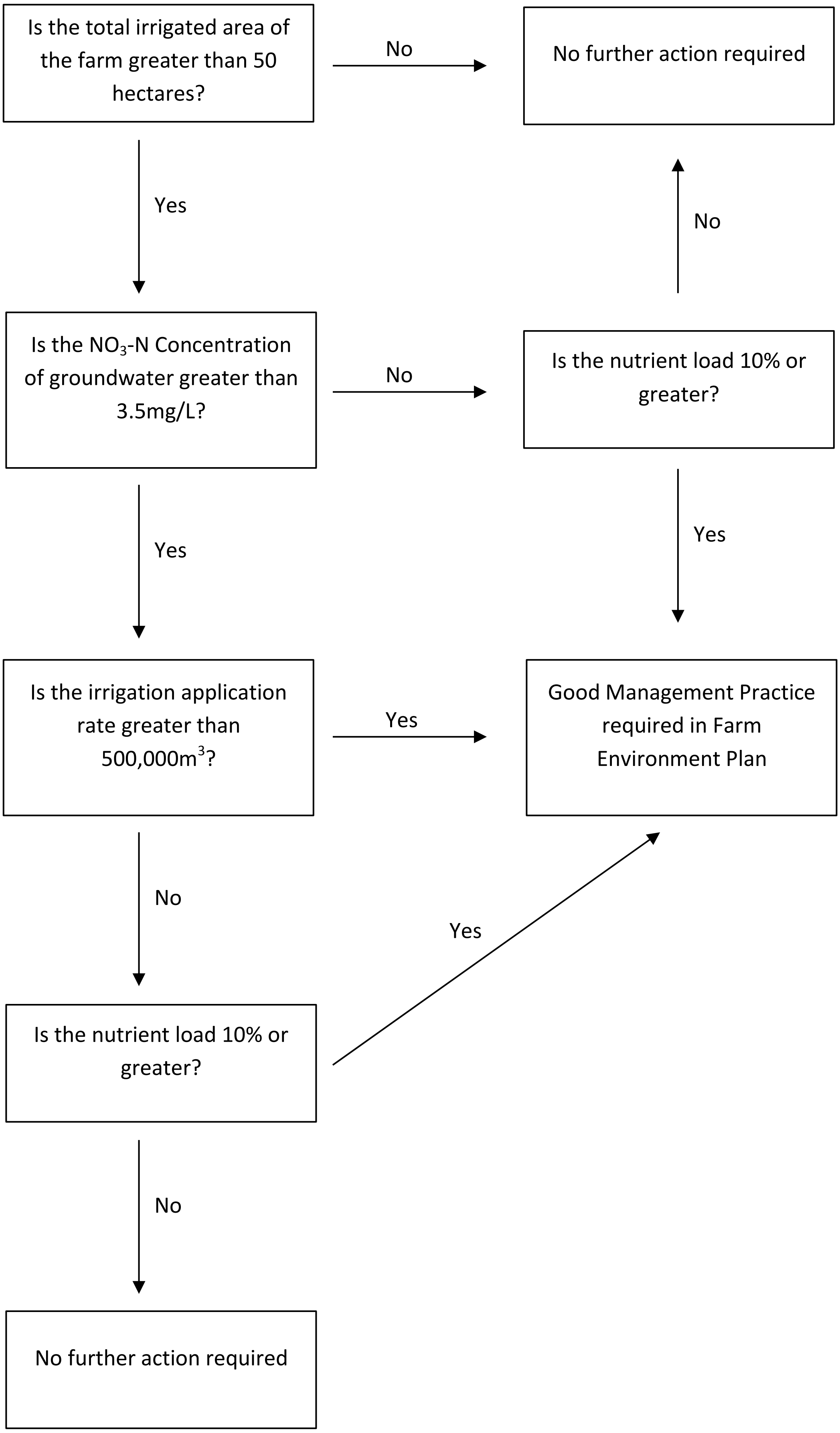


Figure 39: Decision tree used to determine if farmers should consider irrigation nitrogen contribution in their FEPs.

4.5.4. Liquid Fertiliser or Solid Fertiliser Choice

The nitrogen that is added to farmland from groundwater could be considered as a form of liquid fertiliser. Most fertiliser is applied in solid forms but liquid fertiliser can be advantageous. Farmers often want to improve the growth of crops or pasture by applying nitrogen fertilisers using the most efficient method possible.

The way plants uptake fertiliser is considerably important when deciding to choose solid or liquid fertilisers. When solid fertiliser is applied to land, it requires gravity, rainfall, irrigation and stock trampling to get it to filter through to the soil and be taken up in the plant's roots (Quin, 2012). Nitrogen fertilisers are converted firstly to nitrate in the soil before they are taken up by the plant (Lynch, 1882, Quin, 2012). However, these granules may stay on the surface for weeks before this occurs (Quin, 2012). Therefore, solid fertiliser is more susceptible to being removed from the surface before entering the soil.

Foliar feeding is a method that plants use to uptake fertiliser through their leaves which can only be done with the application of liquid fertilisers. The difference in these two forms of uptake is that the leaves of a plant have a protective layer of cuticle wax that is used for protection against insects, dust and excess moisture loss (Quin, 2012). This makes it difficult for the plant's leaves to uptake the nutrients unless soluble products are applied (Quin, 2012). Urea is one form of solid fertiliser that is difficult to be utilised by plant leaves as it is not soluble. Foliar application allows for more efficient and effective application of liquid fertilisers as growth is stimulated. Therefore, this is where liquid fertilisers and in particular nitrogen from groundwater could be valuable for the growth of crops and pastures.

Urea is a nitrogen solid fertiliser that is commonly used by most farmers as it is convenient and has a reasonable cost (Quin et al., 2015). However, only 30 to 50 percent is consumed by plants per application, making it less efficient (Quin, 2012). The rest is volatilized as ammonia, emitted as a nitrous oxide greenhouse gas or leached as nitrate (Quin, 2012). This research hopes to reduce the leaching of nitrate by reusing the amount that is present in the groundwater as an alternative to using fertilisers such as urea. Therefore, by using nitrogen in the groundwater as an alternative, nitrate leaching would be reduced and the efficiency of nitrogen uptake by the plant's leaves will be increased.

4.5.5. Incorporating Use of Nitrogen Contribution in Groundwater into Farming Practices

When incorporating this research into every day farming practices, it is important to consider attitudes farmers will have towards implementation. From the farmers that participated in this research, the attitude was positive and most people were interested in the nitrate concentrations that were present in their groundwater supply. Having someone come onto the farm and make these measurements was more convenient for farmers as their time is often restricted. These farmers all had an interest in the environment and how they could sustain their land while still maintaining maximum profitability. Therefore, potentially other farmers in Canterbury are going to have a similar attitude towards the possibility of looking into ways to improve nitrogen management on their farm. Many farmers in the Canterbury region have been in the agriculture industry for generations so they have an understanding of the land better than anyone else which needs to be strongly considered.

Monaghan, Hedley, Di, McDowell, Cameron & Ledgard (2007) highlighted some issues that farmers consider when making decisions on whether or not to have new developments on their farm which included: cost, complexity and compatibility with the farm system present. Cost has already been discussed above and it was concluded that fertiliser costs would be reduced up to 21 percent and no additions to current irrigation systems are necessary. Although there is no complexity to physically adding the nitrogen to land, farmers will need to firstly measure NO_3-N concentrations to calculate their nitrogen contribution (i.e. nutrient load) which may be difficult. Farmers already have access to measuring NO_3-N concentrations through accredited laboratories (i.e. Hills Laboratories & McMillan Laboratory located in Canterbury) and most have water meters that record irrigation application rates. Therefore, the complex part may be determining the contribution of nitrogen to land by using the nutrient load calculation. The two variables need to be converted into the same unit before they can be calculated. Once the nutrient load is determined this can be compared to the amount of nitrogen fertiliser applied on farm and used to decide how much can be partially replaced by nitrogen in the irrigation water. This research is also highly compatible with any farm system as the nitrogen in the groundwater is already traveling through the irrigator onto the paddock, requiring minimal effort.

To implement this research, efficient and effective education will be required to reduce any complexity and uncertainty for farmers. Therefore, it needs to be determined who exactly will be appropriate to implement this GMP. In September 2015, several industry partners developed a document called 'Industry-agreed Good Management Practices relating to water quality' which outlined GMPs that farmers could adopt through a project called The Matrix of Good Management (MGM). These industries include ECan, the Foundation for Arable Research (FAR), New Zealand Pork, DairyNZ, Beef and Lamb New Zealand, Horticulture New Zealand and the Deer Industry New Zealand. It is suggested that these industries could also support the use of nitrogen in groundwater as a partial alternative to fertiliser. Other dairy industries including Fonterra and Synlait may also be useful in educating their shareholders on how this GMP could be used on dairy farms to reduce nitrogen losses.

These industries have the responsibility to aid farmers in environmental and resource management. There has been a considerable amount of work done by each industry to improve the water quality in Canterbury which is sometimes overlooked by the media and unfortunately changes the perception the public has of farmers. By developing projects like the MGM project these industries can reach a wide range of farmers to reduce their footprint and look to manage environmental risks on their farm more efficiently.

It is inevitable that with the increase of agriculture in the region that fertiliser use and stocking rates will increase nitrogen losses from farms. However, agriculture contributes to approximately 70 percent of New Zealand's export earnings so it is not economically feasible to stop farming (Ministry of Primary Industries, 2013). Therefore, there is a need to maintain both the environment and agriculture industry without trading one off for the other.

4.6. Uncertainties of OVERSEER®

It was anticipated that the nitrogen losses in Scenario 3 would decrease more significantly in comparison to Scenario 1 and 2 by using accurate nitrogen information measured in this research. However, this was not the case as OVERSEER® does not consider the efficiency of using highly concentrated nitrogen in groundwater for irrigation and the recycling of nutrients. Therefore, this may have caused no significant changes in the nitrogen losses between all three scenarios. Solid nitrogen fertiliser application would be reduced and the nitrogen in the groundwater would instead be recycled back onto the farm which should be considered as a GMP. This GMP as well as others could be an aspect that is included in future modelling of nutrient budgets in OVERSEER®.

OVERSEER® has the ability to calculate the amount of nutrients that are added to the farm from irrigation on a kg/ha/year basis. This was similar to the nutrient load calculation that was used to determine the contribution of nitrogen from groundwater to each farm. However, the accuracy of the OVERSEER® calculation could be questionable as it does not take into consideration the actual amount of irrigation water applied within a season. An updated version of OVERSEER® was released in late April 2015 which included a new irrigation module. This allowed farmers to account for the type of irrigation system (i.e. centre pivots, laterals, or boarder dyke irrigation) as well as how irrigation application is scheduled on the farm. However, OVERSEER® does not ask for the amount of water applied during a season even though the majority would know this as Canterbury farms are required to meter their water use. This could be an aspect that OVERSEER® may look to improve in the future as the model is always updating. Thus, it was decided that the nutrient load calculation would provide more reliable results as the actual irrigation application rate was used to determine nitrogen contribution from groundwater.

Unfortunately due to time constraints and the uncertainties in OVERSEER®, nutrient budgets were unable to be produced for two of the three arable farms. It is unknown how accurate the nutrient budget for the arable farm (Farm K) is but it is likely that with future updates of OVERSEER® this uncertainty will be reduced. OVERSEER® has some difficulty with crop rotations which makes producing a nutrient budget a time consuming process compared to dairy farms. OVERSEER® was originally designed to model nutrient losses from pastoral farms and the model has undergone recent changes to adapt to other types of farming including arable (Williams et al., 2013). Pastoral farms will usually have the ground covered throughout the entire year while arable farms have various crop rotations within one year, creating a more complex management system. OVERSEER® uses a plant-soil modelling approach which is appropriate for pastoral and cropping farms as nutrients are generally transferred between the plant and soil (Williams et al., 2013). However, the plant to soil component in arable farming is significantly more difficult than in pastoral farming. Crop management is short term as crop growth will determine when fertiliser and irrigation will be applied. Crop management can vary on a scale of days, weeks to months as according to crop growth (Williams et al., 2013). Instead of asking to input this short term data, OVERSEER® asks for average annual climate data and for the months of when irrigation is applied which is more suitable for pastoral farming as pastures are left in for longer periods (Williams et al., 2013). This may be an area that OVERSEER® is working on for future updates to improve the accuracy of arable farms' nutrient budgets.

These uncertainties as well as others need to be better understood by stakeholders that are or will be using OVERSEER®. Although there are uncertainties, OVERSEER® is currently the best tool that is able to predict nutrient losses from any type of farm for water quality management purposes compared to other models. By inputting more accurate and appropriate information into OVERSEER® uncertainties will definitely decrease in the model which will help with making decisions. It is a model that uses multiple smaller models within it so it is expected that the model will have some indecisions. OVERSEER® has already previously undergone multiple updates to improve its accuracy in predicting nitrogen losses and it is likely that this will continue.

As these updates have been released, the estimated nutrient losses have changed and this was the case with the most recent irrigation module update. Depending on how the irrigation management information was entered this caused a large increase in the predicted nitrogen losses as drainage increased in the model. This increase did not necessarily indicate that more nitrogen was being lost to receiving waters but just that the estimate itself had changed. OVERSEER® expected this to occur but some farmers were surprised by this, suggesting that further explanations were required. Fertiliser companies including Ravensdown and Ballance are already implementing education and training with their clients and are committed to working with them to ensure these uncertainties in OVERSEER® are understood.

4.7. Future NO_3-N Concentrations in the Groundwater

It is currently unknown how reducing fertiliser application and using nitrate in groundwater as an alternative fertiliser will affect future NO_3-N concentrations. As discussed above, groundwater NO_3-N concentrations vary depending on the type of recharge that occurs and this varies across the two districts.

The groundwater in deeper aquifers is significantly older and with the time lags that occur, it is possible that in 20 to 30 years the NO_3-N concentrations will represent the land use changes that are occurring at present. This includes the increase in dairy farming across Canterbury where there has been a shift from fertilisers affecting nitrate levels in groundwater to stock urine patches. Therefore, it is likely that the NO_3-N concentrations in deep groundwater are likely to increase before they improve and water quality increases. This could be apparent in the Ashburton District as the recharge typically comes from the surface and flows through to deeper groundwater aquifers (Hanson & Abraham, 2013). It will also take some time to see the effects of management techniques used to minimise nutrient losses from farms in the groundwater quality as water systems need time to respond to changes.

Since the groundwater in the Selwyn District is primarily recharged from alpine rivers, NO_3-N concentrations may be lower as the nitrate levels are less in these surface waters as land use intensification is minimal in alpine areas. Then again, due to the high interconnectivity between the waters in the Selwyn District, nitrate could leach from land into surface waters and end up in groundwater. Depending on the amount of nitrate that is leached from the surface, which could be significant due to dairy expansion, NO_3-N concentrations could potentially increase.

Reductions in NO_3-N concentrations from using this research would also be dependent on how many farmers decide to use it. If there are a limited number of farms that use the nitrogen in the groundwater to partially replace fertilisers, it is likely that the reductions in nitrate concentrations will be minimal.

5. Conclusions

There were no trends in NO_3-N concentrations between each of the farms chosen to participate in the research. Each farm is case specific and has a number of variables that influence the NO_3-N concentrations measured. This includes groundwater well depth, land use changes that occur on the surface, flow of groundwater in the aquifer system and leaching rates.

The contribution of nitrogen to agricultural land is highly dependent on the NO_3-N concentration measured in the groundwater, the irrigation application rate and the land size applied to. Therefore, farms that had a higher NO_3-N concentration in their groundwater, had a more significant contribution and were able to reduce the amount of nitrogen fertiliser applied to the farm.

It is likely that where farmers have a significant contribution from nitrogen groundwater that can be used as fertiliser, benefits will be observed on the farm. This includes reduced fertiliser costs (up to 21 percent), accurate OVERSEER® nutrient budgets, the application of this research as a GMP in FEPs, and the increased efficiency of using liquid fertilisers. Although the nitrogen losses in OVERSEER® did not change significantly between the scenarios, farmers are still able to reduce their nitrogen fertiliser application which will be useful for nutrient management on farms.

The use of this research as a GMP on farm will be dependent on how farmers perceive and understand it. Therefore, education and training through specific industry groups is necessary for implementation to be successful. Canterbury farmers have shown that they are willing to improve the environment by already implementing many management strategies used to reduce risks. Therefore, there is no doubt that farmers will be open to any other technologies to reduce nitrogen losses from farms to groundwater environments.

5.1. Recommendations

To interpret the changes in NO_3-N concentrations measured on the farms more distinctly, regular monitoring could be continued to determine any significant trends. Annual monitoring of various groundwater wells around Canterbury is not sufficient enough to determine how groundwater concentrations vary and if the differing seasonal aspects affect them. It is considered that any regular monitoring will require time and associated costs.

However, this monitoring is required to get a better understanding of these variations for management purposes. With a better interpretation of the changes in NO_3-N concentrations, more accurate and precise management decisions can be made on how to improve the water quality.

If farmers choose to use nitrogen in the groundwater as an alternative to fertilisers, it is recommended that they regularly monitor their NO_3-N concentrations to allow for any changes that could affect their nutrient load calculation. Farmers will need to provide an accredited laboratory with a water sample to determine the NO_3-N concentration in the groundwater. Nutrient loads will also need to be regularly calculated due to these variations that occur in NO_3-N concentrations and irrigation application rate. This will ensure that farmers are always applying the correct amount of nitrogen needed for plant growth.

5.2. Future Research

Future research could investigate how the plant's growth responds to the application of nitrogen from groundwater as an alternative to nitrogen fertiliser. This could be executed by setting up various trials to compare the use of nitrogen from groundwater as a fertiliser to the application of common solid nitrogen fertilisers (i.e. urea). Various plant types (i.e. crops and pastures) could be used with various nitrate concentrations in the irrigation water and applied at different rates. These trials will likely indicate if the nitrogen in the irrigation water is sufficient enough to partially replace solid fertiliser use as according to plant growth.

Further research could also include looking into modelling the movement of groundwater on the Canterbury Plains to determine how nitrogen concentrations might become more diluted in the future. By recycling the nitrogen in the groundwater it is likely that the nitrogen concentrations would decrease as the nutrient is essentially being recycled through the system. However, further research is required to determine if these dilution effects are likely and the magnitude of nitrogen concentration reductions.

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Appendix

Appendix 1: Information Sheet given to farmers.

Waterways Centre for Freshwater Management
Telephone: +64 3
Email: sarah.hayman@pg.canterbury.ac.nz
27 February 2015

Nitrogen Addition to Agricultural Land by Groundwater Used For Irrigation in the Ashburton & Selwyn Districts

Information Sheet for Selected Farmers

My name is Sarah Hayman and I am currently a postgraduate student in the Waterways Centre for Freshwater Management at the University of Canterbury. As part of the final year of my university studies, I will be completing my master's thesis in Water Resource Management. My research will involve quantifying the amount of nitrogen that is added to farmland via irrigation from groundwater to determine if it is sufficient enough to replace nitrogen (i.e. fertilisers) that leaves agricultural land. With recent nutrient limits that have been set by zone committees as part of the Canterbury Water Management Strategy, this project will involve calculating the total input of nitrogen onto a farm to compare to the amount of nitrogen added via irrigation. Once the data and calculations have been analysed, these figures will be compared to the zone committee's nutrient limits and recommendations for farmers will be made on limit load setting. This research will be focused in the Selwyn and Ashburton Districts which are subject to these nutrient limits. As I have grown up in the Ashburton District my whole life and have worked in the Selwyn District, I understand the importance of farming and the affect these nutrient limits will have on every day farming processes, which is why this project is important to me.

You have been asked to participate in this research as you are situated in the selected research area and your irrigation supply is predominantly from groundwater wells. Your farm also has a relatively high nitrogen input therefore you will be subject to the nutrient limits that have been set under the Canterbury Water Management Strategy.

Your involvement in this project will be to provide data for over the past 5 years (including this irrigation season) on the following:

- Groundwater well samples to test for nitrogen present
- Annual irrigation application rate
- Annual nitrogen input onto agricultural land (i.e. fertiliser)
- Annual application of effluent irrigated onto land (if applicable)
- Information on soil type

Upon completion of this project, you will receive a copy of the results and findings for your own use.

Participation is voluntary and you have the right to withdraw at any stage without penalty. If you choose to withdraw before the analysing of the data, I will remove information relating to you from the project.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public without your prior consent. To ensure anonymity and confidentiality, only my supervisor and I will have access to this data and it will be securely stored in a password protected electronic form. After this project has been completed, the data will be stored for 5 years before it is permanently destroyed. A thesis is a public document, so once completed it will be available through the UC Library.

You will also have the opportunity to choose if you would like your name used in the final document. If you decide that you do not wish to have your name made public, codes will instead be used to protect the information and your identity.

This project is being carried out as a requirement of my Masters in Water Resource Management thesis under the supervision of Professor Jenny Webster-Brown, who can be contacted at jenny.webster-brown@canterbury.ac.nz. She will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee, and participants should address any complaints to The Chair, Human Ethics Committee, University of Canterbury, Private Bag 4800. Christchurch (human-ethics@canterbury.ac.nz).

If you agree to participate in the study, you are asked to please complete the consent form attached to this information sheet and return to my email – sarah.hayman@pg.canterbury.ac.nz.

Thank you for taking the time to consider participating in this project, it is very much appreciated. If you have any further questions regarding this project, please do not hesitate to contact me on the above details.

Kind regards

Sarah Hayman

Appendix 2: Consent Form given to farmers upon participation.

Waterways Centre for Freshwater Management
Telephone: +64 3
Email: sarah.hayman@pg.canterbury.ac.nz

Nitrogen Addition to Agricultural Land by Groundwater Used For Irrigation in the Ashburton & Selwyn Districts

Consent Form for Selected Farmers

Include a brief statement regarding each of the following:

I have been given a full explanation of this project and have had the opportunity to ask questions

Yes/No

I understand what is required of me if I agree to take part in the research.

Yes/No

I understand that participation is voluntary and I may withdraw at any time without penalty. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

Yes/No

I understand that any information or opinions I provide will be kept confidential to the researcher and that may published or reported results will not identify the participants. I understand that a thesis is a public document and will be available through the UC Library.

Yes/No

I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form and will be destroyed after five years.

Yes/No

Do you wish to have your name used in the final document that will be made public? If no, do you understand that codes will instead be used to protect the information provided and your identity?

Yes/No

I understand the risks associated with taking part and how they will be managed.

Yes/No

I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

Yes/No

I understand that I can contact the researcher Sarah Hayman at sarah.hayman@pg.canterbury.ac.nz or supervisor Professor Jenny Webster-Brown at jenny.webster-brown@canterbury.ac.nz for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (human-ethics@canterbury.ac.nz).

By signing below, I agree to participate in this research project.

Signature: ___________________________________ Date: ______________________

Please return this form to sarah.hayman@pg.canterbury.ac.nz by [*DATE TO BE PUT IN*]

Kind regards

Sarah Hayman

Appendix 3: Data request form given to farmers during data collection.

Data Request Form by Farmers

Information required from Farmers:

- Nitrogen concentrations in the groundwater used for irrigation
  This data should be provided in the format that you receive it in, however if this information is not available, access to the well will be needed to sample the groundwater to determine the concentration. This will involve finding a suitable time as requested by the farmer. To allow for the seasonal changes in groundwater, it is likely that a sample will be taken every month for 6 months to allow for this.

- Annual irrigation application rate
  This data should be provided in the format that you receive it in. This should include irrigation that occurred for the entire season (e.g. 2014/2015 irrigation season).

- Annual nitrogen input onto agricultural land
  This data should be provided in the format that you receive it in. Nitrogen inputs could include fertiliser, stock effluent or supplementary feeds. If possible, could this figure just include the total nitrogen.

- Annual application of effluent irrigated onto land (if applicable)
  It is likely that this may only be applicable for dairy farms. This data should also be provided in the format that you receive it.

- Size of area applied to
  This includes the size of the area that the irrigation and nitrogen is applied to on the farm.

- Information on soil type
  This could include information such as the permeability of the soil, water holding capacity of the soil, density, leaching rate, and type of sediment.

If possible, we would like this information to cover the past 5 years. However, we do understand that some participants may have converted their farm within this time frame. Therefore, where this is the case it is asked that you only supply the information that you have.

It is anticipated that this data be returned within two weeks of it being requested. Otherwise, it is understood that the participants are relatively busy so if this information could be returned when convenient. This information can be returned either by email, post or during a site visit. If returning by post, please use the address below:

Sarah Hayman
Waterways Centre for Freshwater Management
University of Canterbury
Private Bag 4800
Christchurch
New Zealand

Thank you for all your help with this project, it is very much appreciated. If you have any further enquires please do not hesitate to contact me to discuss these. My contact details are below.

Kind regards

Sarah Hayman
University of Canterbury
Email: seh113@uclive.ac.nz
Mobile: 027 505 3631

Appendix 4: Nutrient loads calculated for each farm from five years of data (ID = Incomplete Data, NDA = No Data Available, NIA = No Irrigation Applied).

Farm A (Upper Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mm/year)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	4.3	4300.0	543	727620	3128.8	23.3	300 ± 10	134	7.2
2013/2014	4.3	4300.0	309	414060	1780.5	13.3	300 ± 10	134	4.2
2012/2013	4.3	4300.0	456	611040	2627.5	19.6	300 ± 10	134	6.1
2011/2012	4.3	4300.0	ID	NDA	NDA	NDA	300 ± 10	134	NDA
2010/2011	4.3	4300.0	ID	NDA	NDA	NDA	300 ± 10	134	NDA
5 Year Average:	4.3	4300.0	436	584240	2512.2	18.7	300 ± 10	134	5.9

Farm B (Upper Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	2.55	2550	918,902	2,343	14	202.2	173.1	6.3
2013/2014	2.55	2550	517,312	1,319	8	346	173.1	2.2
2012/2013	2.55	2550	815,158	2,079	12	252	173.1	4.5
2011/2012	4.3	4300	686,894	2,954	17	262	173.1	6.1
2010/2011	4.4	4400	873,770	3,845	22	287	173.1	7.2
5 Year Average:	3.27	3270	762,407	2,508	14	269.84	173.1	5.3

Farm C (Upper Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	3.8	3839	710378	2727.1	18.9	165.3	144.5	10.2
2013/2014	5	5000	594213	2971.1	20.6	181.09	144.5	10.2
2012/2013	5.2	5200	657840	3420.8	23.7	263	144.5	8.3
2011/2012	6	6000	487919	2927.5	20.3	318	144.5	6.0
2010/2011	5.1	5120	653084	3343.8	23.1	362	144.5	6.0
5 Year Average:	5.0	5032	620686.8	3011.6	21.3	257.878	144.5	8.1

Farm D (Upper Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mg/m3)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	1.7	1700	1606334	2661.9	10.2	195.8	260	5.0
2013/2014	1.3	1300	1033989	1344.2	5.2	284.578	260	1.8
2012/2013	1.3	1300	1326993	1725.1	6.7	247	258.9	2.6
2011/2012	5.1	5100	942027	4804.3	17.5	210	275.1	7.7
2010/2011	3.6	3600	1376939	4957.0	18.0	322	275	5.3
5 Year Average:	2.6	2600	1257256.4	3098.5	11.5	251.9	265.8	4.5

Farm E (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mm/year)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Fertiliser Nitrogen Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	1.4	1433.3	500	800000	1146.7	7.2	143	160	4.8
2013/2014	1.4	1433.3	500	800000	1146.7	7.2	242	160	2.9
2012/2013	1.4	1433.3	556	889600	1275.1	8.0	351	160	2.2
2011/2012	1.4	1433.3	312	499200	715.5	4.5	354	160	1.2
2010/2011	1.4	1433.3	632.2	1011520	1449.8	9.1	325	160	2.7
5 Year Average:	1.4	1433.3	500.04	800064	1146.8	7.2	283	160	2.8

* For 2013/2014 & 2014/2015 Irrigation Seasons - an average between the previous 3 seasons were used to get these figures

Farm F (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Fertiliser Nitrogen Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	1.1	1050.0	947213	994.6	5.1	150	195	3.3
2013/2014	1.2	1210.0	862956	1044.2	5.4	134	195	3.8
2012/2013	1.1	1050.0	750000	787.5	4.0	150	195	2.6
2011/2012	1.1	1050.0	750000	787.5	4.0	150	195	2.6
2010/2011	1.1	1050.0	750000	787.5	4.0	150	195	2.6
5 Year Average:	1.1	1082.0	812033.8	880.3	4.5	146.8	195	3.0

Farm G (Pond Water) (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	0.3	256	756015	193.7	1.4	249	136	0.6
2013/2014	0.3	256	NDA	NDA	NDA	NDA	136	NDA
2012/2013	0.3	256	NDA	NDA	NDA	NDA	136	NDA
2011/2012	0.3	256	NDA	NDA	NDA	NDA	136	NDA
2010/2011	0.3	256	NDA	NDA	NDA	NDA	136	NDA
5 Year Average	0.3	256.25	756015	193.7	1.4	249	136	0.6

Farm H (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	6.3	6316.25	1463954	9246.7	43.2	250	214	14.7
2013/2014	6.3	6316.25	789332	4985.6	23	252	214	8.5
2012/2013	6.3	6316.25	1290803	8153.0	38	260	214	12.8
2011/2012	6.3	6316.25	ID	NDA	NDA	251	214	NDA
2010/2011	6.3	6316.25	NDA	NDA	NDA	240	214	NDA
5 Year Average:	6.3	6316.25	1181363	7461.8	34.9	250.6	214	12.0

Farm I (Block 1) (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mm/ha)	Annual Irrigation (m3/ha/year)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	7.7	7690.4	245.0	2450.0	68600.0	527.6	18.8	191	28	9.0
2013/2014	7.7	7690.4	103.3	1033.3	28933.3	222.5	7.9	46	28	14.7
2012/2013	7.7	7690.4	168.3	1683.3	47133.3	362.5	12.9	313	28	4.0
2011/2012	7.7	7690.4	46.7	466.7	13066.7	100.5	3.6	15	28	19.3
2010/2011	7.7	7690.4	193.3	1933.3	54133.3	416.3	14.9	161	28	8.5
5 Year Average:	7.7	7690.4	151.3	1513.3	42373.3	325.9	11.6	145.2	28	11.1

Farm I (Block 2) (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mm/ha/year)	Annual Irrigation (m3/ha/year)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	8.5	8534.5375	195	1950	42900	366.1	16.6	191	22	8.0
2013/2014	8.5	8534.5375	80	800	17600	150.2	6.8	285	22	2.3
2012/2013	8.5	8534.5375	175	1750	38500	328.6	14.9	15	22	49.9
2011/2012	8.5	8534.5375	175	1750	38500	328.6	14.9	122	22	10.9
2010/2011	8.5	8534.5375	225	2250	49500	422.5	19.2	122	22	13.6
5 Year Average:	8.5	8534.5375	170	1700	37400	319.2	14.5	147	22	17.0

Farm I (Block 3) (Lower Selwyn Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (mm/ha/year)	Annual Irrigation (m3/ha/ year)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/ year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	6.7	6742.2	225	2250	67500	455.1	15.2	57	30	21.0
2013/2014	6.7	6742.2	70	700	21000	141.6	4.7	61	30	7.2
2012/2013	6.7	6742.2	175	1750	52500	354.0	11.8	86.5	30	12.0
2011/2012	6.7	6742.2	195	1950	58500	394.4	13.1	66	30	16.6
2010/2011	6.7	6742.2	360	3600	108000	728.2	24.3	78	30	23.7
5 Year Average:	6.7	6742.2	205	2050	61500	414.6	13.8	69.7	30	16.1

Farm J (Upper Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	4	4040	947711	3828.8	22.4	223	171	9.1
2013/2014	4	4040	862956	3486.3	20.4	223	171	8.4
2012/2013	4	4040	905334	3657.5	21.4	223	171	8.8
2011/2012	4	4040	905334	3657.5	21.4	223	171	8.8
2010/2011	4	4040	905334	3657.5	21.4	223	171	8.8
5 Year Average:	4	4040	905333.8	3657.5	21.4	223	171	8.8

Farm K (Pond Water) (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	1.6	1632.9	2,000,000	3265.7	7.6	174	430	4.2
2013/2014	1.6	1632.9	NDA	NDA	NDA	NDA	NDA	NDA
2012/2013	1.6	1632.9	NDA	NDA	NDA	NDA	NDA	NDA
2011/2012	1.6	1632.9	NDA	NDA	NDA	NDA	NDA	NDA
2010/2011	1.6	1632.9	NDA	NDA	NDA	NDA	NDA	NDA
5 Year Average:	1.6	1632.9	2,000,000	3265.7	7.6	174	430	4.2

Farm L (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	7.0	7000	3890422	27233.0	47.0	255	580	15.5
2013/2014	8.85	8850	3890422	34430.2	78.3	270	440	22.5
2012/2013	7.0	7000	3890422	27233.0	61.9	270	440	18.6
2011/2012	7.0	7000	3890422	27233.0	61.9	270	440	18.6
2010/2011	7.0	7000	3890422	27233.0	61.9	270	440	18.6
5 Year Average:	7.4	7370	3890422	28672.4	62.2	267	468	18.8

Farm M (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)3	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	3.6	3625	850000	3081.3	14.7	225	210	6.1
2013/2014	3.6	3625	850000	3081.3	14.7	225	210	6.1
2012/2013	3.6	3625	850000	3081.3	14.7	225	210	6.1
2011/2012	3.6	3625	850000	3081.3	14.7	225	210	6.1
2010/2011	3.6	3625	850000	3081.3	14.7	225	210	6.1
5 Year Average:	3.6	3625	850000	3081.3	14.7	225	210	6.1

Farm N (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	2.4	2400	2808718	6740.9	22.2	281	303	7.3
2013/2014	2.4	2400	1015796	2437.9	8.0	312	303	2.5
2012/2013	2.4	2400	1390131	3336.3	11.0	236	303	4.5
2011/2012	2.4	2400	1122320	2693.6	8.9	261	303	3.3
2010/2011	2.4	2400	783865	1881.3	6.2	273	303	2.2
5 Year Average:	2.4	2400	1424166	3418.0	11.3	272.6	303	4.0

Farm O (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	2.9	2883.3	794,096	2,290	10	280	230	3.4
2013/2014	2.9	2883.3	541,677	1,562	7	153.1	230	4.2
2012/2013	2.9	2883.3	NDA	NDA	NDA	NDA	NDA	NDA
2011/2012	2.9	2883.3	NDA	NDA	NDA	NDA	NDA	NDA
2010/2011	2.9	2883.3	NDA	NDA	NDA	NDA	NDA	NDA
2 Year Average:	2.9	2883.3	667,887	1,926	8	216.55	230	3.8

Farm P (Lower Ashburton Catchment)

Irrigation Season (Year)	Nitrogen Concentration (mg/L)	Nitrogen Concentration (mg/m3)	Annual Irrigation (m3/year)	NO3-N via Irrigation (kg/year)	NO3-N via Irrigation (kg/ha/year)	Annual Nitrogen Fertiliser Input (kg/ha/year)	Land Size Applied to (ha)	% Irrigation N Contribution
2014/2015	2.2	2225.0	150422.4	334.7	2.2	350	154.4	0.7
2013/2014	2.2	2225.0	80870.4	179.9	1.2	393	154.4	0.4
2012/2013	2.2	2225.0	NIA	NDA	NDA	184	154.4	NDA
2011/2012	2.2	2225.0	NIA	NDA	NDA	200	154.4	NDA
2010/2011	2.2	2225.0	80611.2	179.4	1.2	200	154.4	0.4
5 Year Average:	2.2	2225.0	103968	231.3	1.5	265.4	154.4	0.5

Appendix 5: Measurements of Other Water Parameters.

Farm A (Upper Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.3	98	12.5	7.2	142.5
2	10.58	99.4	8.7	7.54	154.6
3	11.4	98.3	8.9	7.25	154.5
4	10.49	97.4	11.2	7.77	170.8
5	9.88	94.5	11.5	7.54	150.6
6	7.93	73	11	7.3	149
7	7.26	79.8	18	7.6	138
8	7.93	84.2	16	7.63	141.4

Farm B (Upper Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	3.97	37.3	12	0	98.6
2	5.72	56.4	12.6	8.78	95.3
3	5.26	42.2	5	7.91	92.1
4	15.94	130.6	6.5	7.38	162.4
5	0	0	12	7.48	161.6
6	9.73	92.2	0	0	0
7	8.67	87.4	14	7.58	157.9
8	8.95	88.7	14	7.42	163.5

Farm C (Upper Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	7.52	70.2	11.3	0	139.7
2	10.61	96.4	7.7	7.58	156.5
3	6.7	49.8	2	7.25	149.9
4	8.59	66.4	2.6	7.72	143.6
5	9.66	93.1	12.5	7.4	170.5
6	9.91	92.9	11.7	7.5	160.1
7	8.53	90.9	16	7.4	159.1
8	8.8	91.5	13	7.5	150.4

Farm D (Upper Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (°C)**	**pH**	**Conductivity (µS/cm)**
1	9.66	91.2	11.2	8	114.9
2	10.44	95.4	11.2	7.58	120.7
3	10.63	97.6	11.4	7.99	134.5
4	10.34	98	12	8.14	119.5
5	10.16	98.9	12.5	8.02	113.9
6	9.36	95.5	14	8.11	119.6
7	9.87	98.3	14	7.93	108.2

Farm E (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (°C)**	**pH**	**Conductivity (µS/cm)**
1	8.42	83.4	15	7.75	195
2	8.38	82.2	14	8.09	220
3	8.02	80.6	16	8.25	211

Farm F (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature (°C)**	**pH**	**Conductivity (µS/cm)**
1	8.49	88.9	15.6	6.5	118.3
2	7.86	70.7	10	7.6	154.4
3	5.92	55	12.3	8.19	0
4	9.75	92.3	13.6	7.76	140.4
5	9.51	92.5	13.8	7.81	137.8
6	3.1	29.4	12.5	8.29	135.6
7	2.2	25.6	20	8.86	140.4
8	5.09	51.6	15.5	8.13	169.8

Farm G (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.74	102.6	12.4	7.5	101.3
2	6.69	59.1	9.1	7.38	90.4
3	10.42	87.6	7.8	7.4	107.2
4	11.23	98.7	10.3	7.66	117.2
5	10.55	97.8	12.2	7.93	108.4
6	10.1	96.5	13.2	7.87	113.9

Farm G (Pond Water) (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	9.76	100.2	15	8.22	54.6
2	12.3	102.4	6.1	7.23	54.5
3	12.7	100.9	7	6.88	58.2
4	12	102	8.5	7.56	64.5
5	11.76	107.3	11.5	7.69	61.6
6	10.55	102.1	13.5	7.7	63.7
7	8.12	106.5	25.5	7.47	70.9
8	10	107.8	18.5	7.7	64.7

Farm G (Surface Water) (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	9.7	96.6	14.4	8.06	55
2	11.65	99.5	7.5	6.82	59.5
3	12.87	100.7	5.3	7.07	62.1
4	12.48	103.5	7	7.81	65.3
5	11.56	10.33	10	7.78	63.3
6	10.95	100.1	11	7.85	60.5

Farm H (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.87	88.5	14.6	7.32	236
2	9.4	87.6	11.7	8.66	133.5
3	5.92	55	12.3	8.19	136.2
4	2.32	21.7	12.7	8.72	0
5	0	0	0	0	0
6	10.08	98.1	13	7.79	222
7	10.06	99.2	14	7.89	221
8	10.21	100	14	7.27	221

Farm I (Block 1) (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.41	81.9	13.5	0	242
2	9.97	93	12	7.15	270
3	9.57	89.8	13	6.88	267
4	9	85.7	13.5	7.08	260
5	7.75	78.2	13	7.02	257
6	7.98	79.7	14	7.19	249
7	7.99	82.3	15.5	7.11	244
8	8.78	83.2	14.5	7.44	243

Farm I (Block 2) (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.71	83.2	13	0	284
2	9.63	90.3	12	7.03	315
3	9.35	86.1	12.5	6.83	315
4	9.46	88.3	13	6.96	307
5	9.26	88.5	13	7.01	300
6	9.32	88.4	12.5	7.06	292
7	8.45	86.1	15.5	7.09	240
8	8.75	84.9	14.3	7.13	220

Farm I (Block 3) (Lower Selwyn Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.51	79.4	12.2	0	233
2	9.11	85.3	12	7.03	257
3	10.06	86.4	9.3	6.85	246
4	9.14	85.1	12.8	7.06	249
5	9.14	87	13.3	7	247
6	8.91	84.6	12.5	7.12	241
7	8.91	88.2	15	7.16	283
8	9.19	90.2	14	7.17	238

Farm J (Upper Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	9.46	80.4	8.2	6.55	202.7
2	9.36	81.9	7	6.24	203.4
3	9.74	82.1	7	6.5	200.4
4	9.84	89.5	10.5	6.37	199.9
5	9.97	91.5	11.2	6.47	201.7
6	9.24	79.8	10.9	6.27	205.7

Farm K (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	9.77	9.12	12.3	7.86	189.9
2	2.2	20.5	11.2	7.75	150
3	9.59	91.4	11.5	7.98	187.4
4	9.89	92.3	12.2	8.13	192.8
5	10.07	96.8	12.5	8.15	192.3
6	9.78	93.6	12.5	8.15	197.5

Farm K (Pond Water) (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	9.67	92.5	15	8.29	155
2	14.65	125.4	8	8.06	170.5
3	11.6	102.8	10	8.18	171.6
4	10.25	105.5	14.8	8.53	176.9
5	9.78	93.6	12.5	8.15	197.5
6	9.82	104.7	18.9	8.1	118.8
7	10.25	102.7	14	8.3	167

Farm K (Surface Water) (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	11.26	98.5	8.1	8.25	58.2
2	15.62	131.6	7.7	7.96	57.4
3	12.02	106.4	9	8.12	66.6
4	10.65	101.2	13	8.07	51.4
5	11.45	112.3	12.4	8.17	62.3

Farm L (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature**	**pH**	**Conductivity (µS/cm)**
1	9.32	83.4	9	7.48	243
2	13.34	109.4	6.4	7.83	228
3	10.34	91.9	9.7	8.49	232
4	9.94	93	12.3	7.71	243
5	8.86	90.3	15	7.99	224
6	10.25	90.9	15.5	7.95	230

Farm M (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/L)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	11.08	95.5	6.5	7.18	181.5
2	10.65	96.5	16.2	7.56	176.8
3	10.15	101	15.5	7.65	181.5
4	9.31	101.3	19	7.6	163.3
5	9.93	110.4	19	7.98	153.7
6	10.76	102.3	18.7	7.87	167.9

Farm N (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.66	91.5	12.3	7.57	157.3
2	4.8	45.4	12.4	6.91	226
3	8.55	90.6	12.6	7.27	202
4	8.26	89.8	11.8	7.54	201.4
5	6.84	77.7	12	7.27	141.3
6	8.25	90.9	18	7.63	158
7	8.65	90.8	15	7.31	180.1

Farm O (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	8.44	83	14	7.51	163
2	9.355	95.4	15.1	7.515	188.35
3	4.2	40.9	13	7.09	201.3
4	7.5	68.3	11.4	7.5	186.6
5	7.86	78.1	14	7.71	182.6
6	8.95	97	17	7.29	194.6
7	8.04	76.9	14	7.74	174.4

Farm P (Lower Ashburton Catchment)					
Reading	**Dissolved Oxygen (mg/)**	**% Saturation**	**Temperature (^{O}C)**	**pH**	**Conductivity (µS/cm)**
1	10.04	100.2	12	7.27	114.5
2	9.67	98.3	11.7	7.69	126
3	9.56	95.2	12	7.56	117.2
4	9.43	94.4	13	7.92	121.7
5	9.54	95.5	13.6	7.81	125.8